LABORATORY PERFORMANCE OF RECYCLED ASPHALT CONCRETE

by

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Master's Thesis

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CHAPTER I

INTRODUCTION

For the past 20 years, many states have been aware of the need for the rehabilitation of old asphaltic roads. It has been known that the materials in place, aggregate and asphalt, were free and reusable but the cost of removing and replacing was considered marginal in starting anew. Consequently the materials were merely pushed aside or hauled away.

However, the current inflation in cost of construction materials, primarily as a result of the recent energy crisis and aggregate shortages, has driven the cost of hot mix asphalt concerete and associated asphalt pavement components to phenomenal prices. This situation has forced many pavement engineers to consider the alternative of recycling the aging and brittle pavements.

HISTORY

Recycling technology is not new. The use of asphalt rejuvenators for early stages of pavement distress is well established, and successful experiences with them are recorded in technical literature and patents.[1,2,3,4,5,6,7,8,9,10,11] Early approaches to reclaiming pavements were directed towards reconstituting the physical condition of a mix to make it mechanically workable.

The first time a combined physical and chemical approach to reclaiming asphalt was used, which takes the performance and aging into account, was reported by Rostler and co-workers.[1,4,5,7,10]

CURRENT PROGRESS

In recent years it has been demonstrated that recycling is

economically feasible and desirable. A wide variety of recycling approaches have emerged since the 1930's. Categorization of recycling approaches is usually based on 1) the recycling procedure utilized, 2) the type of paving materials to be recycled and the end products they are to produce or 3) the pavement structural benefit to be gained from the recycling approach. Each of these categories has its own merit in describing the purpose and applicability of a given type of recycling.

Definitions for these categories of recycling have been discussed by the Federal Highway Administration Demonstration Project No. 39 Technical Advisory Committee.[12] The definitions presented below are based on these discussions together with those of the NCHRP Synthesis Panel Members.

Surface Recycling: Rework of the surface of a pavement to a depth of less than about one inch by heater-planer, heater-scarifier hot planing or cold planing devices. This operation is a continuous, single pass, multi-step process which may involve the use of new materials including aggregate, additives and/or mixtures.

As recycling is practiced to a greater extent, equipment manufacturers will develop new machines especially designed for surface recycling, which will reduce construction costs to a minimum. Advertisements for this type of equipment are already appearing in trade journals.[13,14,15,16]

In-Place Surface and Base Recycling: In-place pulverization to a depth greater than about one inch followed by reshaping and compaction. This operation may be performed with or without the addition of an additive or heat.

Typical of this category of recycling is a project completed in 1975 by the Texas Highway Department[17] where the operation and reference to the

equipment used are described in detail.

Central Plant Recycling: Scarification of the pavement material, removal of the pavement from the roadway after or prior to pulverization, processing of material with or without the addition of an additive followed by laydown and compaction to desired grade. This operation may involve the addition of heat depending upon the type of material recycled and the additive utlized.

A description of a recycling procedure typical of this category is contained in a recent paper by Dunning, Mendenhall and Tischer.[18]

CURRENT RESEARCH

Advancements in the mechanics of recycling an aged pavement have led to research efforts directed primarily at understanding the parameters involved in restoring an aged pavement to a condition equivalent to one produced with virgin materials.[13] Although routine design procedures have been suggested and utilized for converting a deteriorated pavement into a workable durable mix, little data are available as to the expected performance of these recycled materials.

It is the objective of this research to 1) utilize a practical laboratory test system for evaluating the performance of recycled asphalt pavement, and 2) evaluate the results for possible correlation with current design concepts for the recycling of deteriorated asphalt pavements utilizing the addition of rejuventaing agents.

CHAPTER 2

MATERIALS

In February 1977 approximately 250 pounds of aged asphalt concrete pavement was removed from three locations on 87th Avenue N.E. in King Co., Washington. This site was selected because the pavement had been in service for approximately 15 years and was believed to be representative of one of the most extreme cases to be encountered in practice.

AGED PAVEMENT

In the laboratory the old pavement was crushed utilizing a six inch jaw crusher adjusted to a maximum jaw opening of one inch. After crushing, material from each of the three locations was screened to determine if the graduation of the crushed material varied with the different locations. As may be seen in Figure 1, the gradation of the crushed pavement remained fairly consistent. The average gradation of the crushed samples are presented in Table 1.

ASPHALT

A sample of the aged pavement was sent to Texas A & M University for laboratory analysis of the asphalt cement properties. The results of standard tests on the asphalt are presented in Table 2.

AGGREGATE

A sieve analysis was conducted on the mineral aggregate recovered from hot solvent extractions. As may be seen in Table 3, the results of the sieve analysis indicated that the average gradation of the mineral aggregate in the pavement mixture was generally within the specification limits of the Washington Class B gradation requirements.

When the average gradation of the mininal aggregate was plotted on a gradation chart with the sieve sizes raised to 0.45 power it was noted that the mixture was "fine graded" when compared with Fuller's modified maximum density reference curve for asphalt mixtures. So as to reduce the number of variables it was considered necessary to control the gradation and density of the specimen mixture. Therefore it was determined that an additional 214 grams of appropriately graded aggregate, Table 4, would be added to each specimen mixture to achieve a specimen gradation that would more closely conform to the modified maximum density curve for asphalt mixtures and allow the asphalt film to surround each particle of aggregate without producing an unstable mixture. The average gradation, the modified maximum density curve and the final aggregate gradation to be utilized in laboratory specimens is contained in Figure 2. The aggregate added to the specimens was considered to be equivalent to the original aggregate used in the pavement mix.

ASPHALT REJUVENATING AGENTS

Asphalts are fractionated into two subdivisions, asphaltenes and maltenes. The function of the asphaltenes is to serve as a bodying agent. Maltenes is the collective name for the remainder of the bitumen material left after precipitation of the asphaltenes. Asphalt is the cementing agent in asphalt pavement. It represents the component that experiences premature hardening as a result of oxidation. During the process of weathering or oxidation, the ratio of maltenes to asphaltenes is reduced with the result being a dry and brittle pavement. If a rejuvenating agent is to be successful, it must contain sufficient maltenes fractions of asphalt in order to improve and restore the maltenes to asphaltenes ratio.

The rejuvenating agents selected for use in this research are as follows:

1. Paxole 1009

   Viscosity at 140° F. 225 cp.

2. Reclamite, Cyclepave

   Viscosity at 140°F. 110 cp.

These commercial rejuvenating agents are composed of a petroleum resin-oil base and have a record of satisfactory service as an asphalt rejuvenating agent; such satisfactory service being based on the capability of the material to increase the ductility and penetration and lower the viscosity of the asphalt binder in the pavement.

CHAPTER III

RESEARCH APPROACH

REJUVENATING AGED ASPHALT CONCRETE PAVEMENT

It has been shown that a reasonable measure of the effect of a rejuvenating agent on an aged asphalt can be had by observing the change in viscosity and penetration effected by addition of increasing amounts of reclaiming agents. There is some indication that the viscosity of treated asphalt is a better indicator of the rejuvenating effect than the penetration test.[20]

It has also been demonstrated that the asphalt viscosity at 140°F. is dependent on the concentration and consistency of the rejuvenating agent and a plot of the viscosity of asphalt at 140°F. versus percent rejuvenating agent on semilog graph paper exhibits a straight line relationship.[18,19] It is on this basis that the amounts of rejuvenating agent were selected for testing purposes.

The viscosity blend chart in Figure 3 assumes the linear relationship of viscosity versus percent rejuvenating agent and shows the change in asphalt viscosity at 140°F. effected by addition of increasing amounts of various rejuvenating agents to the asphalt. It is clear that when the viscosity of the aged asphalt is high in relation to that of the rejuvenating agents, the viscosity of the mixture is extremely sensitive to the amount and consistency of rejuvenating agent present in the mixture. It is equally clear that rejuvenating agents of higher viscosity will permit considerably more flexibility in the amount of agent which can be added to the mix.

As shown in Figure 3, the viscosity of the aged asphalt and the

viscosity of the selected rejuvenating agent are plotted to determine the amount of rejuvenating agent required in the blend to achieve asphalt viscosities in the range of paving grade asphalt, i.e. AR - 1000 --- AR-16000.

After determining the boundaries within which the viscosities of rejuvenated asphalt were similar to the viscosities of paving grade asphalt, laboratory specimens were fabricated containing the material quantities calculated in Table 5, wherein the amount of rejuvenating agent was increased from 0.0% to 1.5% of total mix in increments of 0.5%. Specimens were also fabricated using a standard AR-4000 and AR-2000 paving grade asphalt to provide a basis for comparison subsequent to conditioning and mechanical testing.

PERFORMANCE FACTORS

Although the addition of rejuvenating agents to aged and brittle asphalt has shown favorable results towards reconstituting the physical conditions of a mix, little data is available as to the expected performance of the recycled mixture.

Highway pavement performance relies to a large degree on the phenomenon of adhesion between asphalt cement and aggregate particles. The performance is influenced by many factors, such as asphalt characteristics, aggregate properties, mix design, construction procedures, environmental conditions, and traffic. The vast amount of field experience indicates that the presence of moisture in combination with the other factors is most critical with regard to pavement performance and the related phenomenon of adhesion between the asphalt cement and the aggregate particles. Therefore,

in order to measure the performance of recycled asphalt concrete pavements it was necessary to adopt a laboratory testing system that would subject laboratory specimens to about the worst moisture condition that could exist in the field. Inasmuch as pavement design is based at least partly on worst condition, it would then be reasonable to obtain mechanical properties of a uniform mixture containing varied amounts of rejuvenating agent at selected stages of accelerated conditioning.

SPECIMEN CONDITIONING

R. P. Lottman, University of Idaho, developed a practical laboratory test system for quantitatively predicting magnitude and rate of moisture damage in asphalt concrete to simulate field conditions using accelerated test conditioning.[21] The test system utilized vacuum submerged saturation for water intrusion into laboratory specimens, followed by a moisture conditioning procedure for specimens using several freeze-thaw thermal cycles. Previous work in Idaho by Lottman,[22,23] showed that a temperature cycle ranging from 0^{o} to 120^{o}F. (-18^{o} to 49^{o}C.), when repeated 18 times on saturated asphalt concrete specimens, will produce stripping damage in the mix, similar to the damage experienced in the field. Based on this work and findings these temperature extremes were selected for use in conditioning the specimens fabricated for testing under this research. The number of freeze-thaw cycles, however, was reduced from 18 to 12 since the overall effect on conditioning was not considered significant due to the reduction.

In progressing from laboratory experiments to field operations involving mixing of reclaiming agents with asphalts, it should be kept in mind that certain reactions take place which are governed by time, temperature

and degree of mixing. The fluxing of asphalt contained in an asphalt-aggregate mixture with a rejuvenating agent is a physico-chemical phenomenon. Fluxing of two ingredients, asphalt and reclaiming agent, is easily accomplished in the laboratory by means of heating and mixing in a matter of minutes. In order to gain an understanding of the fluxing process, a duplicate group of specimens were also fabricated and placed in an oven at 140°F. and held for increasing periods of time. At the end of selected time intervals, the specimens were subjected to mechanical testing similar to the specimens that underwent thermal cycle accelerated conditioning.

PERFORMANCE EVALUATION

In order to evaluate the performance of the recycled asphalt concrete specimens, it was decided that the nondestructive resilient modulus (M_R) test reported by Schmidt would be used to study the changes in strength.[24] The theoretical basis for this test has been shown by mathematical analysis[25,26] (assuming plane stress) that a uniform compressive load applied perpendicular to the horizontal diametral plane of a thin disk gives rise to a uniform tensile stress over the vertical diametral plane containing the applied load. A simplified mathematical treatment was given by Frocht[25] who supported his mathematics by photoelastic analyses of plastic disks.

When this approach is applied to dynamically loaded disks or cylinders, it is possible to determine the elastic modulus of the material. This is accomplished by measuring the elastic deformation across the horizontal diameter resulting from the application of a load along the vertical diameter. An expression[27] for the elastic modulus, E, can be developed

as follows.

Frocht[25] gives expressions for the stresses, σx and σy, across the diameter, d, perpendicular to the applied load, P.

$$\sigma x = [2P/\pi td\ (d^2-4x^2)/(d^2+4x^2]^2$$

$$\sigma y = -2P/\pi td\ [4d^4/(d^2+4x^2)^2 -1]$$

where t is the thickness of the disks, and x is the distance from the origin along the abscissa. A typical distribution of these stresses is shown in Figure 4. Assuming plane stress and elastic behavior, the expression for the strain, εx, across the diameter is

$$\varepsilon x = 1/E\ [\sigma x - \nu\ (\sigma y + \sigma z^{o})]$$

where ν is the Poisson's ratio.

By substituting in the preceding expression for σx and σy, the following expression is derived

$$\varepsilon x = 2P/E\pi td\ \ [4d^4\nu - 16d^2\ x^{\ 2})/(d^2+4x^2)^2 + (1 - \nu)]$$

The total deformation is given by integrating the strain between $\pm$ d/2:

$$\Delta = \int_{-d/2}^{d/2} \varepsilon x\ dx$$

where Δ = total deformation across the specimen.

By substituting for εx and integrating between the limits $\pm$ d/2.

$$\Delta = P/tE\ [(4/\pi) + \nu -1]$$

By substituting and solving for E,

$$E = P(\nu + 0.2732)/t\Delta \qquad \text{(Eq. 1)}$$

Therefore, if the horizontal deformation across a cylinder resulting from an applied vertical load is known, the modulus of elasticity can be calculated.

For purely elastic materials, Eq. 1 should apply for either static or dynamic loadings. For viscoelastic materials, such as asphalt concrete, Eq. 1 should apply reasonably well if the loading time is short enough so that viscous effects are small. Under short-duration dynamic loads on a viscoelastic material, the apparent Young's modulus, E, is frequently defined as the resilient modulus, M_R, the material property useful to multilayer elastic or finite element structural design methods. The M_R testing procedure provides a means of determining the dynamic load, P, and the total deformation, Δ. These values are entered in Eq. 1, where M_R is assumed equal to E.

$$E \approx M_R = P\ (\nu + 0.2732)/_{t\Delta}$$

A range of values for Poisson's ratio can be assumed without excessive error in the calculated M_R. A value of 0.35 for ν has been shown to be reasonable for asphalt concrete specimens.[24] The M_R obtainable with this test would not only provide a basis for comparing the performance of specimens containing rejuvenated asphalt to specimens containing virgin paving grade asphalt but it would also permit the practical consequences of changes to M_R to be estimated using the multilayer elastic or finite element design method.

CHAPTER IV

TEST PROCEDURES

In addition to summarizing the test procedures utilized for this research, information pertinent to the test procedure is included as a help in the understanding of the procedure.

1. Preparation of Laboratory Specimens

Laboratory specimens were fabricated by blending selected amounts of rejuvenating agents with appropriate amounts of crushed pavement and additional aggregate such that the total asphalt content, asphalt cement plus rejuvenating agent, and the aggregate weight and gradation would remain reasonably uniform throughout all the test specimens.

It should be noted that in order to maintain a reasonably constant asphalt content it was necessary to decrease the amount of crushed pavement, thereby decreasing the asphalt cement to allow for the addition of rejuvenating agent. However, decreasing the amount of crushed pavement also resulted in a proportional decrease in the aggregate amount and a change in aggregate gradation. Therefore, a proportional increase in the amount of aggregate was required to adjust and maintain a reasonably constant aggregate gradation.

Table 5 presents the required proportions of the salient components of each laboratory specimen necessary to achieve reasonable uniformity among the specimens.

Prior to compaction, appropriate amounts of crushed pavement and additional aggregate were heated in a 275^{o} oven for one hour. During the last 15 minutes of the period a specified amount of rejuvenating agent was placed in a closed container and heated in a water bath to approximately

$200^{\circ}F$. At the end of one hour the rejuvenating agent was added to the crushed pavement and mixed thoroughly to insure that the rejuvenating agent was blended with the asphalt and that the additional aggregate was properly coated with asphalt cement. The mixture was then covered and placed back in the 275° oven for 30 minutes prior to compaction.

Laboratory specimens were prepared in accordance with WSHD Test Method No. 702A utilizing the California Kneading Compactor. This method for preparation of test specimens is similar to ASTM Designation: D1561. The compactor foot pressure was reduced to 350 psi to minimize crushing of aggregate during compaction and a "leveling load" of 12,650 lbs. for a period of one minute was applied using a single plunger. All other procedures were standard for this method. Specimens were then allowed to cure at $73^{\circ}F$. for approximately two weeks prior to vacuum saturation. Table 6 and 7 contain miscellaneous laboratory data on each group of specimens.

2. Vacuum Saturation

Specimens were placed in a vacuum chamber filled with water. A vacuum was applied at 26-inch Hg for thirty minutes. The vacuum was removed and the specimens were allowed to remain submerged for thirty minutes. (Note: Dry weights, submerged weights, and surface dry weights can also be made before and after this procedure for purposes of calculating permeable voids and density).

3. Thermal Cycle Accelerated Conditioning

An automatic cycle air temperature chamber was used to produce this conditioning. Chamber air temperature was set at $0^{\circ}F$. and $120^{\circ}F$., and the

cyclic timer was set for 4-hour intervals in tripping at $0^{o}F$. and at $120^{o}F$. In other words, a complete cycle of 0^{o} - 120^{o} - $0^{o}F$. was timed at eight hours; four hours per half cycle. Chamber characteristics showed less then thirty minutes for the air to reach $0^{o}F$. or $120^{o}F$. and therefore the air remained at $0^{o}F$. or $120^{o}F$. for slightly more than 3 1/2 hours. Under these conditions it has been found that specimens placed in the chamber would reach $0^{o}F$. or $120^{o}F$. in slightly over three hours, and would remain about forty minutes at each temperature.[21]

Following vacuum saturation specimenswere wrapped in plastic and placed in the cycle air temperature chamber. For this procedure, specimens were left surface moist and each covered separately and tightly with two layers of plastic film. This film was taped to each specimen. Each specimen was then placed in a plastic bag containing approximately 10 ml. of water. The bag was then sealed and the wrapped specimens were placed flat on the shelves of the cyclic air temperature chamber and the temperature cycling was started.

Temperature cycling lasted four days (8 hours per cycle x 12 cycles). To help insure an even distribution of moisture inside the specimen once a day the chamber was opened and the specimens were turned over.

At the end of selected time intervals and at the conclusion of 12 thermal cycles, the wrapped specimens were removed from the cycle air temperature chamber and prepared for mechanical testing. The objective of moisture conditioning was to saturate the laboratory specimens to bring out their lowest mechanical properties (moisture damage), and to produce laboratory specimens with moisture damage equivalent to that existing in highway pavements. This conditioning process has been shown to fulfill

these objectives.[23]

4. Accelerated Conditioning at 140°F.

Duplicate speciments were fabricated and placed in an oven at 140°F. and held for increasing periods of time. At the end of selected time invervals, the specimens were removed from the oven and prepared for mechanical testing. The purpose of the 140°F. conditioning was to gain an understanding of the physico-chemical phenomenon involved with fluxing asphalt contained in an asphalt-aggregate mixture with a rejuvenating agent and its effect on the mechanical properties of a specimen.

5. Mechanical Testing

Mechanical testing to evaluate and predict the performance of recycled asphalt pavement consisted of performing a nondestructive resilient modulus (M_R) test. This test is similar in some respects to the split tension tests used by Lottman for studying the influence of water on asphalt-treated mixtures.[21] However, instead of testing to destruction to determine the tensile strength of the specimen, a light 0.1-second duration pulsing load is applied across one diameter of a cylindrical specimen while at the same time the resultant elastic deformation across the opposite diameteris measured. The apparatus used for this test is illustrated in Figures 5 and 6.

The M_R device was similar to one developed at the University of Idaho.[21] It consisted of an aluminum plate base with a piece of spring steel attached on two sides of the base and parallel to the long axis of the base loading block. Each piece of spring steel had two strain gauges cemented to it at the point of maximum moment near the fixed end. Figure 6 shows the device used for measuring the horizontal deformation as it

appeared with a specimen in position.

It should be noted that the specimens subjected to thermal cycle accelerated conditioning had small plates with pins cemented to opposite sides of the specimen. When the specimen was positioned in the M_R device the pins fit into receiving slots in the arms of the M_R device. The specimens subjected to accelerated conditioning at 140^oF. were positioned between contact points affixed to the arms of the resilient modulus device.

After positioning the specimen and M_R device in the repetitive loading device a pulsating load was applied across the vertical diameter which resulted in a corresponding elastic deformation across the horizontal diameter. The output from the strain gauges due to the horizontal movements were amplified and recorded on a strip chart recorder. Figure 7 shows a typical trace obtained on an asphalt concrete specimen.

A load duration of 0.1 seconds repeated 20 times a minute was chosen because this loading corresponded to the duration used by a number of investigators.[28,29,30,31] Their various studies included relating laboratory-measured M_R to field behavior within the framework of multilayer elastic design theory. A load duration of 0.1 seconds is considered typical of the load applied in the field by slow-moving traffic. Also nearly three second pauses between load applications permit substantially complete viscoelastic recovery of the specimen. The resilient modulus test was conducted with the specimens at 73^oF.

CHAPTER V

FINDINGS, INTERPRETATION AND APPRAISAL

This research was initiated in an attempt to utilize a practical laboratory test system for evaluating the performance of recycled asphalt pavement and to evaluate the results for possible correlation with current designs concepts for the recycling of deteriorated asphalt pavements utilizing the addition of rejuvenating agents.

Some generally consistent trends have been observed which are illustrated in Figures 8 through 11. It appears significant that for nearly all the specimens in their original state there is an increase in resilient modulus, M_R, as a result of an increase in the maximum stress. It should be noted, however, that this trend is not consistent with the findings of Schmidt,[24] Figure 12, wherein the M_R of asphalt concrete specimens showed a slight decline with an increase in the maximum stress. The increase in M_R experienced with this testing could possibly be due to the initially low M_R and subsequent densification of the specimen, the positioning of the specimens in M_R device or changes in the value of Poisson's ratio. It is interesting to note, however, that the relationship that does exist between the M_R and the maximum stress in most cases appears to exhibit straight line characteristics when plotted on a logarithmic scale. This uniformity would seem to indicate some validity in the relative values of M_R obtained.

Also notable is the difference between the M_R of the specimens presented in Figures 8 and 9 and the group of duplicate specimens presented in Figures 10 and 11. This difference can probably be attributed to the difference in the apparatus utilized for testing the resilient modulus.

It is recognized that the resilient modulus of all the specimens is unusually low. According to an independent test conducted at Texas A&M University the true resilient modulus of the specimens fabricated for this research is approximately twenty times greater than the values obtained from the resilient modulus apparatus utilized in this research. Although the M_R values presented herein represent values much lower than what could be expected, they do serve to indicate relative properties of the specimen and should be analyzed in a relative sense. If further research is to be conducted in this area, it is recommended that the resilient modulus testing device be modified to obtain more accurate results. Appendix A contains a discussion of the resilient modulus testing device utilized for this research along with suggested modifications to the apparatus.

Mechanical Properties Subsequent to Thermal Cycle Accelerated Conditioning

Plots of M_R vs. thermal cycle exposure are shown in Figures 13 and 14 for each set of specimens containing selected amounts of rejuvenating agent. It is noted that a significant reduction in M_R is achieved during the first 3 cycles of freeze-thaw. As shown in Figure 13 the M_R in general continues to decrease in the specimens fabricated with standard AR2000 and AR4000 paving grade asphalt. The specimens containing selected amounts of rejuvenating agents, Figure 14, exhibit a general increase in M_R after the initial 3 cycles of freeze-thaw. It has been found that the drop in M_R obtained on vacuum saturated specimens is reversible when the water is removed.[24] The general increase in M_R after 3 cycles of freeze-thaw could be due to the loss of moisture during testing at the end of 3 cycles combined with the rehabilitating effects of the rejuvenating agents present in the mixture.

The uniformity of the specimens is also worthy of comment. Although the designed asphalt content is 5.2% for each specimen it is likely that the actual asphalt content varies with the amount of asphalt cement present in the crushed pavement that is utilized in the recycling process. Control of the asphalt cement provided by the crushed pavement is difficult in the laboratory and even more difficult in the field. It should also be noted that the percent air voids in the compacted specimens fall in a relatively low range from 1.6% to 2.8%. Therefore, the fluctuation in M_R observed in this group of specimens after the first 3 cycles freeze-thaw could probably be the consequence not only of the varied asphalt content and low voids but also a consequence of a corresponding decrease in water intruded by the vacuum saturation.

Figure 15 shows both the original dry M_R and the M_R after vacuum saturation and 3 cycles of thermal cycle accelerated conditioning. The M_R is plotted against the theoretical viscosity of the asphalt which is obtained from the viscosity blend chart Figure 3. It should be noted that for specimens containing selected amounts of the rejuvenating agent the decrease in M_R, as a result of vacuum saturation and thermal cycle accelerated conditioning, is comparable to the decrease in M_R experienced by the specimens fabricated with standard AR2000 and AR400 paving grade asphalt. The results presented in Figure 15 are significant in that the performance of recycled asphalt pavements is comparable to the performance of standard asphalt pavement.

A more accurate presentation of the foregoing relationship could be had by extracting the asphalt cement from each of the specimens to determine the actual viscosity of the asphalt contained in the specimens. However, the scope of testing and time limitations did not permit such a determination. Therefore the theoretical viscosities were utilized.

Mechanical Properties Subsequent to Accelerated Conditioning at 140^{o}F

Plots of M_R vs. Hours of Exposure at 140^{o}F are shown in Figures 16 and 17 for each set of specimens. It appears significant that the specimens fabricated with standard AR2000 and AR4000 paving grade asphalt showed a gradual decline in M_R while the specimens fabricated with selected amounts of rejuvenating agents showed a gradual decline in the M_R for the first 48 hours of conditioning at 140^{o}F and then exhibited a significant increase in M_R.

In analyzing the results of the accelerated conditioning at 140^{o}F it is possible that the asphalt cement and rejuvenating agent continue to react within the specimen. As the exposure time at 140^{o}F increases, the rehabilitating effect of the rejuvenating agent begins to decline and the asphalt cement once again begins to oxidize and the asphalt becomes harder. Heukelom and Klomp[33] showed that the stiffness or M_R of asphalt concrete is proportional to the stiffness of the asphalt binder. This condition would explain the increase in M_R. It is probable that the M_R will increase when the asphalt reaches a limiting brittle state. The specimens fabricated with AR2000 and AR4000 paving grade asphalt appear to exhibit this effect. After 48 hours of exposure at 140^{o}F the M_R declined appreciably. It is significant to note that aging of the recycled asphalt pavement specimen appears to have been delayed by the presence of rejuvenating agent in the mixtures. Particularly the specimens containing 1.5% rejuvenating agent. These specimens appear to maintain a lower asphalt viscosity for a longer period of time resulting in a lower M_R than the other specimens where the asphalt cement appears to be hardening.

CHAPTER VI

CONCLUSION

Current design concepts for the recycling of deteriorated asphalt pavements utilize the addition of rejuvenating agents to the aged and brittle pavement to produce an asphalt pavement mixture that exhibits properties equivalent to those of an asphalt concrete pavement containing standard paving grade asphalts.

The results of this research indicate that the performance of recycled asphalt concrete pavements is comparable to the performance of standard asphalt concrete pavements. The performance in this research was measured effectively by the relative change in resilient modulus, M_R.

By utilizing the accelerated test conditioning it is possible to predict the performance of recycled asphalt concrete pavement by comparing its performance to that of a standard asphalt concrete pavement. In this regard, recycled asphalt concrete specimens performed equally as well as specimens containing standard paving grade asphalt.

Although the optimum asphalt content is not known for the mixture utilized in this research, the results presented indicate relative damage due to accelerated test conditioning. With additional research in this area it is considered feasible to determine the optimum asphalt content and minimum voids determination by using the accelerated test conditioning in order to minimize damage due to moisture and other environmental conditions.

In completing this research, it is of some importance to question the reproducibility of the test results. The test data presented in this research were obtained from the average of two specimens representing each increment of rejuvenating agent content. In terms of statistical considerations, this is not totally adequate. This does not, however,

disqualify the test data presented herein. The data obtained appeared quite consistent considering the many uncertainties involved in the specimen preparation as well as the general heterogeneity of the material resulting from random distribution of the aggregate particles.

REFERENCES

1. Rostler, F. S., U.S. Air Force Pavement Conference, Berkeley, California, 27-31 July, 1959, pp. 333-354, U.S. Government Printing Office, 1959, 0-52/079/66.

2. Vallerga, B. A., Western Construction, December, 1960.

3. Vallerga, B. A., Western Construction, May, 1962.

4. Vallerga, B.A., Highway Research Record No. 24, Highway Research Board, 1963.

5. Rostler, F. S. U.S. Patent 3,162,101, December 22, 1964.

6. Kinsinger, G., Texas Construction, January 4, 1966.

7. Rostler, F. S., U.S. Patent 3,344,056, September 26, 1967.

8. Canessa, W., Public Works Magazine, November, 1968.

9. Golden Bear Division, Whitco Chemical Corporation, Reclamite Manual for Asphalt Pavement Rejuvenation, January, 1969.

10. Rostler, F. S., U.S. Patent 3,432,321, March 11, 1969.

11. Ronsko, Jr. and Baltzer, G., Public Works Magazine, July, 1976.

12. Federal Highway Administration Demonstration Project No. 39, "Recycling Asphalt Pavements."

13. CMI Corporation, "CMI ROTO-MILL Practical Pavement Recycling."

14. Cutler Repaving, Inc., "Cutler Safe-T-Pave Asphalt Pavement Recycling Equipment."

15. Asphalt Equipment, Inc., of New Mexico, Rural and Urban Roads, September, 1976, p. 46.

16. Anon., Rural and Urban Roads, October, 1976, p. 10.

17. Lindley, B. R., Report No. 613-1, State Department of Highways and Public Transportation, State of Texas, October, 1975.

18. Dunning, R. L., Mendenhall, R. L. and Tischer, K. K., Proceedings, Association of Asphalt Paving Technologists, Vol. 44, 1975, pp. 537-562.

19. Davidson, D. D., Canessa, W., Escobar, S. J., "Recycling of Substandard or Deteriorated Asphalt Pavements -- A Guideline for Design Procedures," Witco Chemical Corp., Golden Bear Division, Oildale, California.

REFERENCES (continued)

20. Air Force Civil Engineering Center, Technical Report 76-3, "Evaluation of Rejuvenators for Bituminous Pavements," Air Force Civil Engineering Center, Tyndall Air Force Base, Florida, February 1976.

21. Lottman, R. P., "Predicting Moisture-Induced Damage to Asphaltic Concrete," Final Report, National Cooperative Highway Research Program, Project 4-8(3), February 1974.

22. Lottman, R. P. and Johnson, D. L., "The Moisture Mechanism that Causes Asphalt Stripping in Asphalt Pavement Mixtures," Second Annual Report, National Cooperative Highway Research Program, Project 4-8(3), 1969.

23. Lottman, R. P., "The Moisture Mechanism that Causes Stripping in Asphaltic Pavement Mixtures," First Annual Report, National Cooperative Highway Presearch Program, Project 4-8(3), 1968.

24. Schmidt, R. J., "A Practical Method for Determining the Resilient Modulus of Asphalt - Treated Mixes," Highway Research Record No. 404, Highway Research Board, 1972.

25. Frocht, M. M., Photoelasticity, Vol. 2, John Wiley and Sons, New York, 1948.

26. Timoshenko, S. and Goodier, J. H., Theory of Elasticity, 2nd Edition, McGraw-Hill, New York, 1951.

27. Merz, P. H., Chevron Research Mathematics Group, 1971.

28. Monismith, C. L. and Deacon, J. A. American Society of Civil Engineering, Transportation Engineering Journal, 1969.

29. Deacon, J. A. and Monismith, C. L., "Laboratory Flexural-Fatigue Testing of Asphalt - Concrete and Emphasis on Compound- Loading Tests," Highway Research Record No. 158, Highway Research Board, 1967.

30. Epps, J. A. and Monismith, C. L., Proceedings, Association of Asphalt Paving Technologists, Vol. 38, 1969.

31. Terrel, R. L., "Factors Influencing the Resilient Characteristics of Asphalt Treated Aggregates, "Ph.D. Dissertation, University of California, Berkeley, 1967.

32. Schmidt, R. J. and Graf, P. E., "The Effect of Water on the Resilient Modulus of Asphalt - Treated Materials," Proceedings, Association of Asphalt Paving Technologists, Vol. 41, 1972.

REFERENCES (continued)

33. Huekelom, W. and Klomp, A. J. G., "Road Design and Dynamic Loading," Proceedings, Association of Asphalt Paving Technologists, Vole. 33, 1964.

BIBLIOGRAPHY

Air Force Civil Engineering Center, Technical Report 76-3, "Evaluation of Rejuvenators for Bituminous Pavements," Air Force Civil Engineering Center, Tyndall Air Force Base, Florida, February 1976.

Anon., Rural and Urban Roads, October, 1976, p. 10.

Asphalt Equipment, Inc., of New Mexico, Rural and Urban Roads, September, 1976, p. 46.

Canessa, W., Public Works Magazine, November, 1968.

CMI Corporation, "CMI ROTO-MILL Practical Pavement Recycling."

Cutler Repaving, Inc., "Cutler Safe-T Pave Asphalt Pavement Recycling Equipment."

Davidson, D. D., Canessa, W., Escobar, S. J., "Recycling of Substandard or Deteriorated Asphalt Pavements--A Guideline for Design Procedures," Wite Chemical Corp., Golden Bear Division, Oildale, California.

Deacon, J. A. and Monismith, C. L., "Laboratory Flexural - Fatigue Testing of Asphalt-Concrete with Emphasis on Compound - Loading Tests," Highway Research Record No. 158, Highway Research Board, 1967.

Dunning, R. L., Mendenhall, R. L. and Tischer, K. K., Proceedings, Association of Asphalt Paving Technologists, Vol. 44, 1975, pp. 537-562.

Epps, J. A. and Monismith, C. L., Proceedings, Association of Asphalt Paving Technologists, Vol. 38, 1969.

Federal Highway Administration Demonstration Project No. 39, "Recycling Asphalt Pavements."

Frocht, M. M., Photoelasticity, Vol. 2, John Wiley and Sons, New York, 1948.

Golden Bear Division, Whitco Chemical Corporation, Reclamite Manual for Asphalt Pavement Rejuvenation, January 1969.

Heukelom, W. and Klomp, A. J. G., "Road Design and Dynamic Loading," Proceedings, Association of Asphalt Paving Technologists, Vol. 33, 1964.

Kinsinger, G., Texas Construction, January 4, 1966.

Lindley, B. R., Report No. 613-1, State Department of Highways and Public Transportation, State of Texas, October, 1975.

Lottman, R. P., "The Moisture Mechanism that Causes Stripping in Asphalt Pavement Mixtures," First Annual Report, National Cooperative Highway Research Program, Project 4-8(3), 1968.

BIBLIOGRAPHY (continued)

______________________, "Predicting Moisture - Induced Damage to Asphaltic Concrete," Final Report, National Cooperative Highway Research Program, Project 4-8(3), February 1974.

Lottman, R. P., and Johnson, D. L., "The Moisture Mechanism that Causes Asphalt Stripping in Asphalt Pavement Mixtures," Second Annual Report, National Cooperative Highway Research Program, Project 4-8(3), 1969.

Merz, P. H., Chevron Research Mathematics Group, 1971.

Monismith, C. L. and Deacon, J. A., American Society of Civil Engineering, Transportation Engineering Journal, 1969.

Ronsko, J. and Baltzer, G., Public Works Magazine, July, 1976.

Rostler, F. S., U.S. Air Force Pavement Conference, Berkeley, California, 27-31 July, 1959, pp. 333-354, U.S. Government Printing Office, 1959, 0-52/079/66.

______________________, U.S. Patent No. 3,162,101, December 22, 1964.

______________________, U.S. Patent No. 3,432,321, March 11, 1969.

______________________, U.S. Patent No. 3,344,056, September 26, 1967.

Schmidt, R. J., "A Practical Method for Determining the Resilient Modulus of Asphalt - Treated Mixes, Highway Research Record No. 404, Highway Research Board, 1972.

Schmidt, R. J. and Graf, P. E., "The Effect of Water on the Resilient Modulus of Asphalt - Treated Materials," Proceedings, Association of Asphalt Paving Technologists, Vol. 41, 1972.

Terrel, R. L., "Factors Influencing the Resilient Characteristics of Asphalt Treated Aggregates," Ph.D. Dissertation, University of California, Berkeley, 1967.

Timoshenko, S. and Goodier, J. N., Theory of Elasticity, 2nd Edition, McGraw-Hill, New York, 1951.

Vallerga, B. A., Highway Research Record No. 24, Highway Research Board, 1963.

______________________, Western Construction, December, 1960.

______________________, Western Construction, May, 1962.

TABLE 1

AVERAGE GRADATION OF AGED PAVEMENT

SAMPLES AFTER CRUSHING

Sieve Size	Crushed Pavement (%) Retained	Crushed Pavement (%) Passing
3/4"	19.2	80.8
1/2"	18.9	61.9
3/8"	15.0	46.9
#4	19.5	27.4
#10	13.2	14.2
#40	11.2	3.2
#80	1.7	1.5
#200	0.9	0.6

TABLE 2

TEST RESULTS ON ASPHALT CEMENT

Test	Result
Extraction: Asphalt Content	6.3%
Penetration	
$4^{o}C$ ($39^{o}F$) 200g - 60 sec	4
$25^{o}C$ ($77^{o}F$) 100g - 5 sec	17
Vicosity	
$24^{o}C$ ($77^{o}F$)	2.8×10^{7} poises
$60^{o}C$ ($140^{o}F$)	21,528 poises
$135^{o}C$ ($275^{o}F$)	7.88 poises
R & B softening point	$60^{o}C$ ($140^{o}F$)
Specific Gravity (Bulk)	2.38

TABLE 3

AVERAGE GRADATION OF AGGREGATE

IN AGED PAVEMENT SAMPLES

Sieve Size	Aggregate (%) Retained	Aggregate (%) Passing	Wash. Class B Specification % Passing
3/4"	0	100	100
1/2"	2.3	97.7	90-100
3/8"	8.7	89.0	75-90
#4	22.5	66.5	55-75
#10	18.7	47.8	32-48
#40	29.2	18.6	11-24
#80	11.3	7.3	6-15
#200	4.9	2.4	3-7
- #200	2.4	0	0-2

TABLE 4

GRADATION OF ADDITIONAL AGGREGATE REQUIRED TO ACHIEVE

MODIFIED MAXIMUM DENSITY FOR LABORATORY SPECIMENS

Sieve Size	Additional Aggregate (%) Retained	Additional Aggregate Weight (214g)	Additional Aggregate (%) Passing
3/4"	0	0	100
1/2"	0	0	100
3/8"	25.2	54.0	74.8
#4	30.8	65.8	44.0
#10	36.9	79.0	7.1
#40	7.1	15.2	0
#80	0	0	0
#200	0	0	0
- #200	0	0	0
		214g	

TABLE 5

DESIGNED COMPOSITION OF LABORATORY SPECIMENS

	Specimens from Crushed Pavement and Rejuvenating Agents				Specimens from Paving Grade Asphalt	
	#1	#2	#3	#4	AR2000	AR4000
Asphalt cement (gm)	64.6	58.3	52.1	45.9	64.6	64.6
Aggregate (gm)	961.4	867.1	774.9	682.7	1175.4	1175.4
Total Crushed Pavement (gm)	1026.0	925.4	827.0	728.6		
*Additional Aggregate 1/2" - #10 214(gm) - (Constant)	214.0	214.0	214.0	214.0	0	0
**Additional Aggregate 3/4" - #200 Adjustment for decrease in Crushed Pavement (gm)	0	94.4	186.6	278.8	0	0
Rejuvenating Agent (gm)	0	6.2	12.4	18.6	0	0
Total Specimen weight (gm)	1240.0	1240.0	1240.0	1240.0	1240.0	1240.0
% Rejuvenating Agent	0.0	0.5	1.0	1.5	0.0	0.0
% Asphalt Cement	5.2	4.7	4.2	3.7	5.2	5.2
Total Asphalt Content (%)	5.2	5.2	5.2	5.2	5.2	5.2

*Additional aggregate required to achieve modified maximum density for laboratory specimens. (Refer to Figure 2)

**Additional aggregate required to maintain aggregate quantity and gradation as a result of a reduction in the amount of crushed pavement in the specimen.

TABLE 6

LABORATORY DATA FOR ASPHALT CONCRETE SPECIMENS PRIOR TO THERMAL CYCLE ACCELERATED CONDITIONING

Specimen No.	Rejuvenating Agent (%)	Specimen Height (in.)	Bulk SP. Gravity	Density (PCF)	Air Voids (%)
AR2-A	0	2.5	2.31	144.1	2.5
AR2-B	0	2.5	2.32	144.8	2.8
AR4-A	0	2.6	2.32	144.8	2.7
AR4-B	0	2.6	2.33	145.4	2.6
1-A	0	2.5	2.40	149.8	1.7
1-B	0	2.5	2.35	146.6	2.4
2-A	0.5	2.5	2.40	149.8	1.4
2-B	0.5	2.5	2.39	149.1	1.7
3-A	1.0	2.5	2.39	149.1	1.9
3-B	1.0	2.5	2.38	148.5	2.1
4-A	1.5	2.5	2.37	147.9	2.2
4-B	1.5	2.5	2.37	147.9	2.1
2-C	0.5	2.5	2.40	149.8	1.4
2-D	0.5	2.5	2.40	149.8	1.3
3-C	1.0	2.5	2.39	149.1	1.7
3-D	1.0	2.5	2.40	149.8	1.6
4-C	1.5	2.5	2.38	148.5	2.2
4-D	1.5	2.5	2.37	147.9	2.2

Note: Specimens AR2-A and B and Specimens AR4-A and B contain AR 2000 and AR 4000 paving grade asphalt respectively.

Specimens 1-A and B contain reheated aged asphalt.

Specimens 2, 3 and 4-A and B contain PAXOLE 1009 as rejuvenating agent.

Specimens 2, 3 and 4-C and D contain RECLAMITE, Cyclepave as rejuvenating agent.

TABLE 7

LABORATORY DATA FOR ASPHALT CONCRETE SPECIMENS PRIOR TO ACCELERATED CONDITIONING AT 140°F

Specimen No.	Rejuvenating Agent (%)	Specimen Height (in.)	Bulk SP. Gravity	Density (PCF)
AR2-C	0	2.5	2.27	141.7
AR2-D	0	2.6	2.29	142.9
AR4-C	0	2.6	2.31	144.1
AR4-D	0	2.6	2.29	142.9
1-E	0	2.5	2.44	152.3
1-F	0	2.5	2.36	147.1
2-E	0.5	2.5	2.38	148.6
2-F	0.5	2.5	2.41	150.1
3-E	1.0	2.5	2.40	150.0
3-F	1.0	2.5	2.39	149.2
4-E	1.5	2.5	2.39	149.2
4-F	1.5	2.5	2.38	148.5
2-G	0.5	2.5	2.42	151.0
2-H	0.5	2.5	2.40	149.7
3-G	1.0	2.5	2.40	150.0
3-H	1.0	2.5	2.41	150.6
4-G	1.5	2.5	2.36	147.4
4-H	1.5	2.5	2.36	147.4

Note: Specimens AR2-C and D and Specimens AR4-C and D contain AR 2000 and AR 4000 paving grade asphalt respectively.

Specimens 1-E and F contain reheated aged asphalt.

Specimens 2,3 and 4-E and F contain PASOLE 1009 rejuvenating agent.

Specimens 2,3 and 4-G and H contain RECLAMITE, Cyclepave rejuvenating agent.

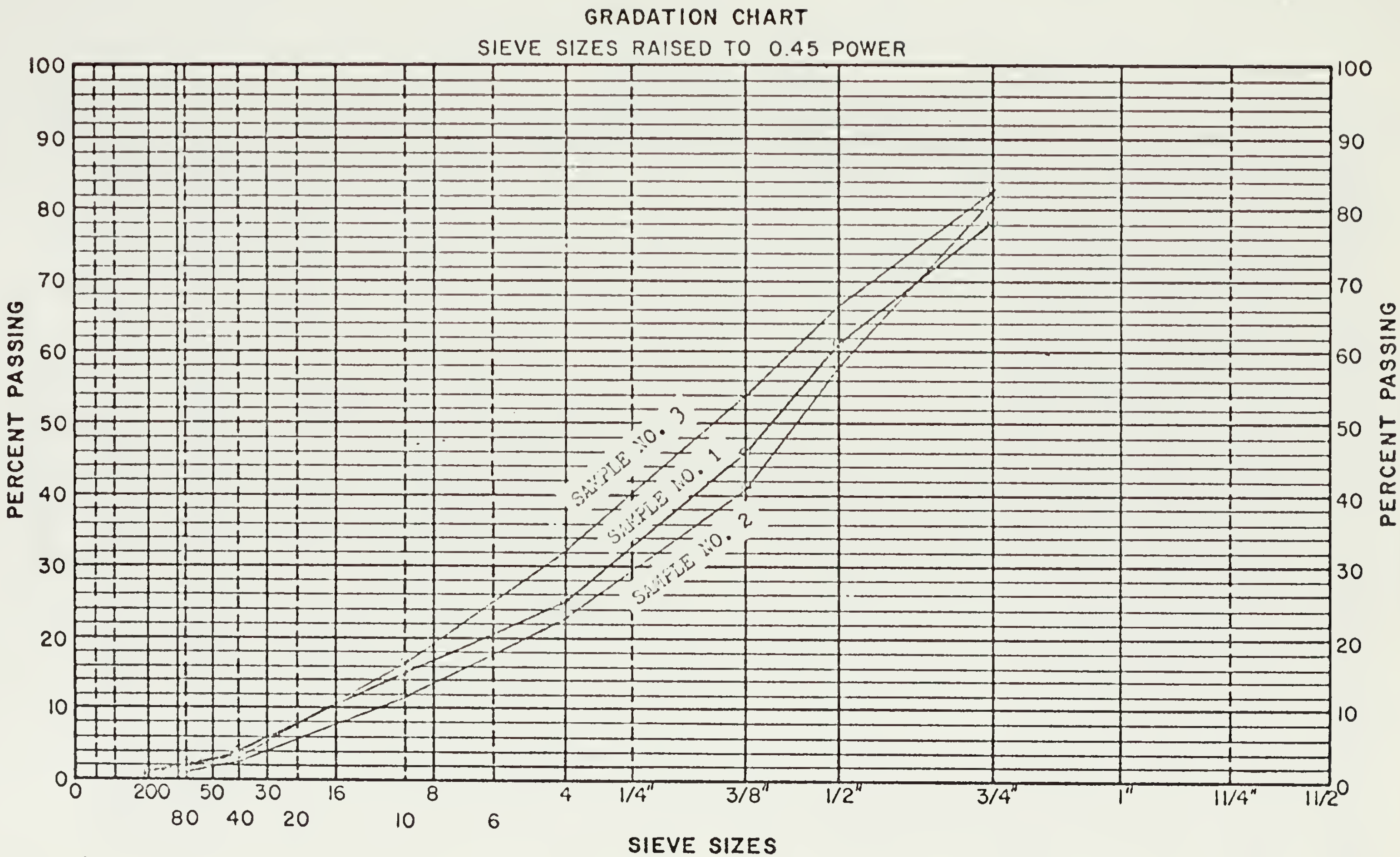


FIGURE 1 Gradation of Aged Pavement Samples After Crushing

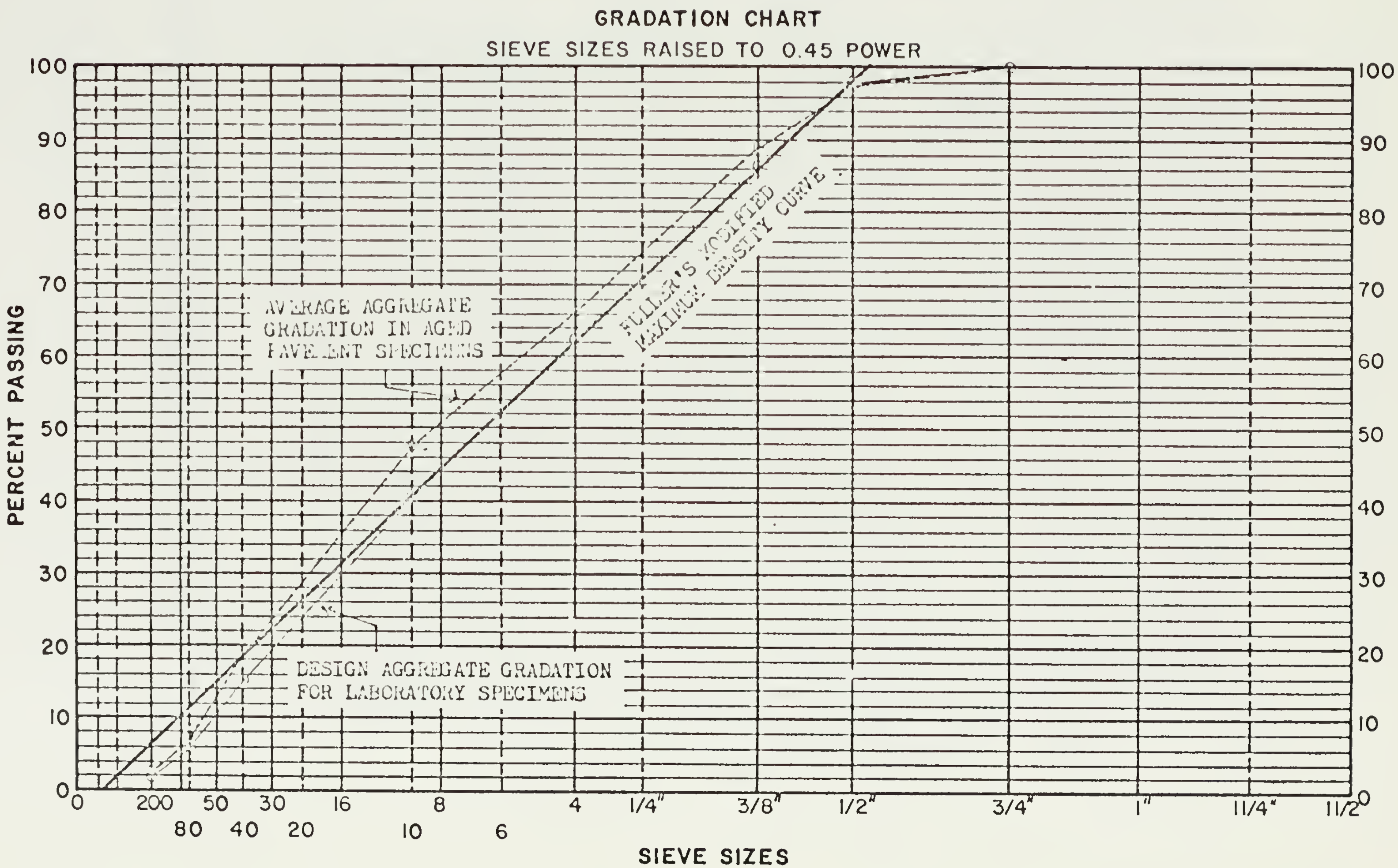


FIGURE 2 Aggregate Gradation for Laboratory Specimens

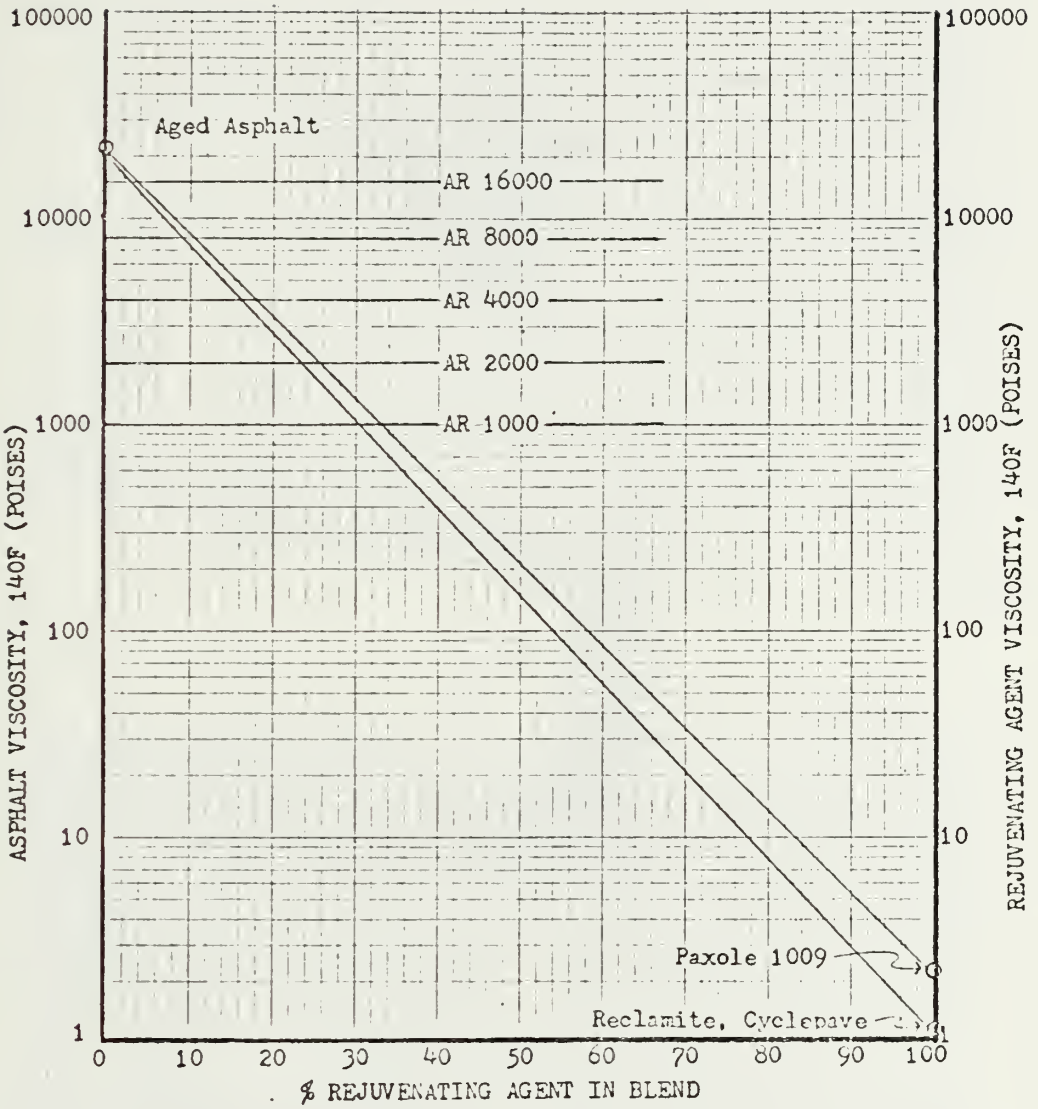


FIGURE 3 Viscosity Relationship of Aged Asphalt and Rejuvenating Agents

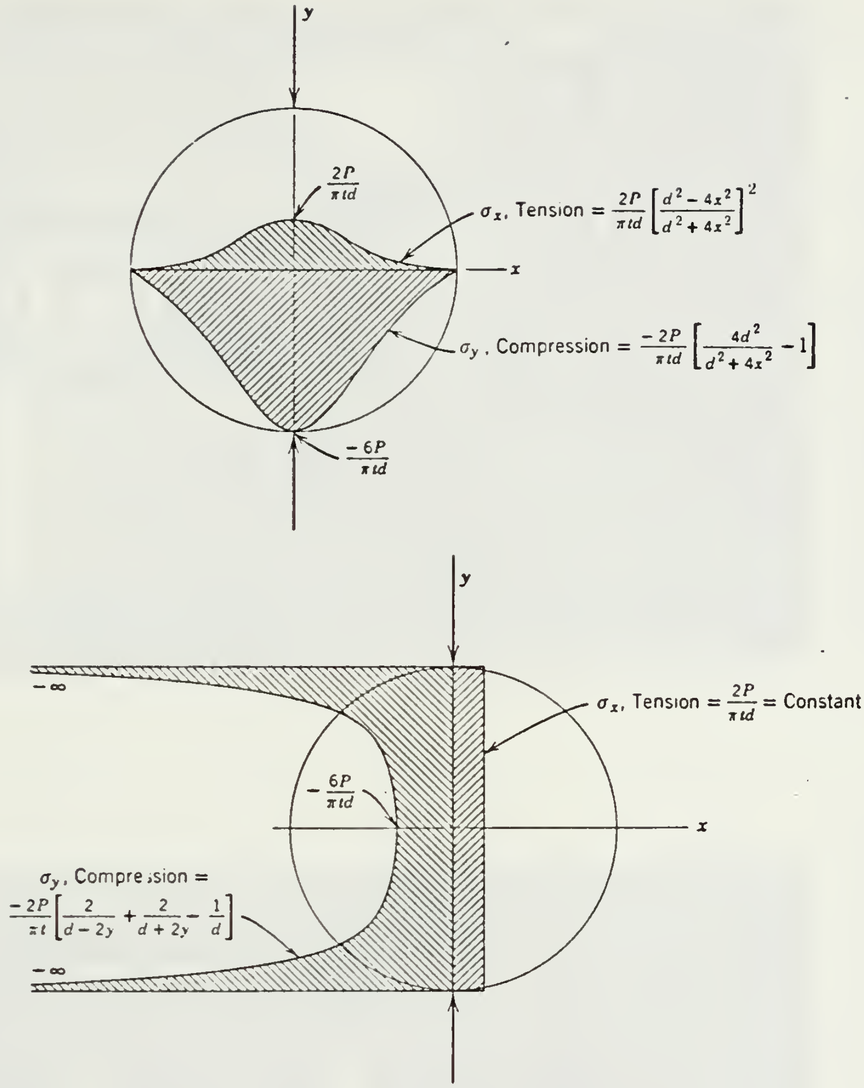
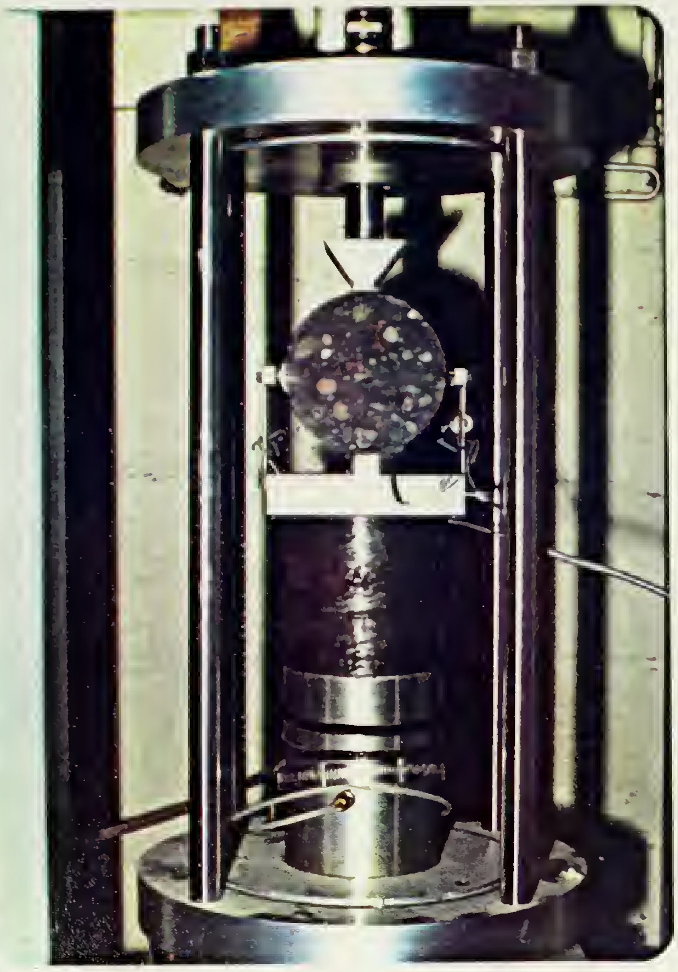
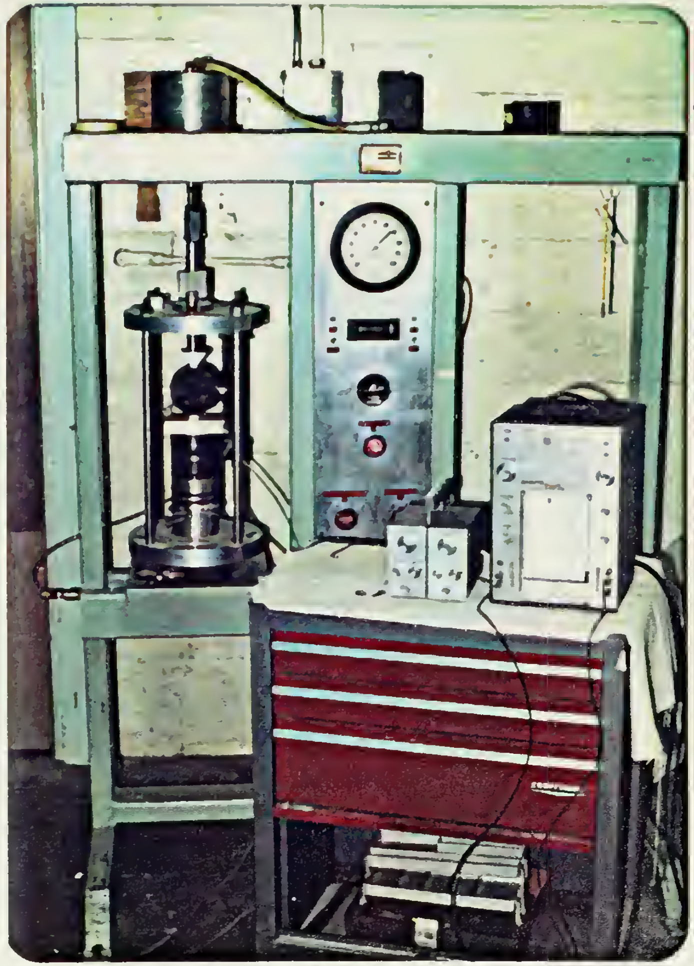


FIGURE 4 Theoretical Stress Distribution on Horizontal and Vertical Diametral Planes for Indirect Tensile Test.[25]

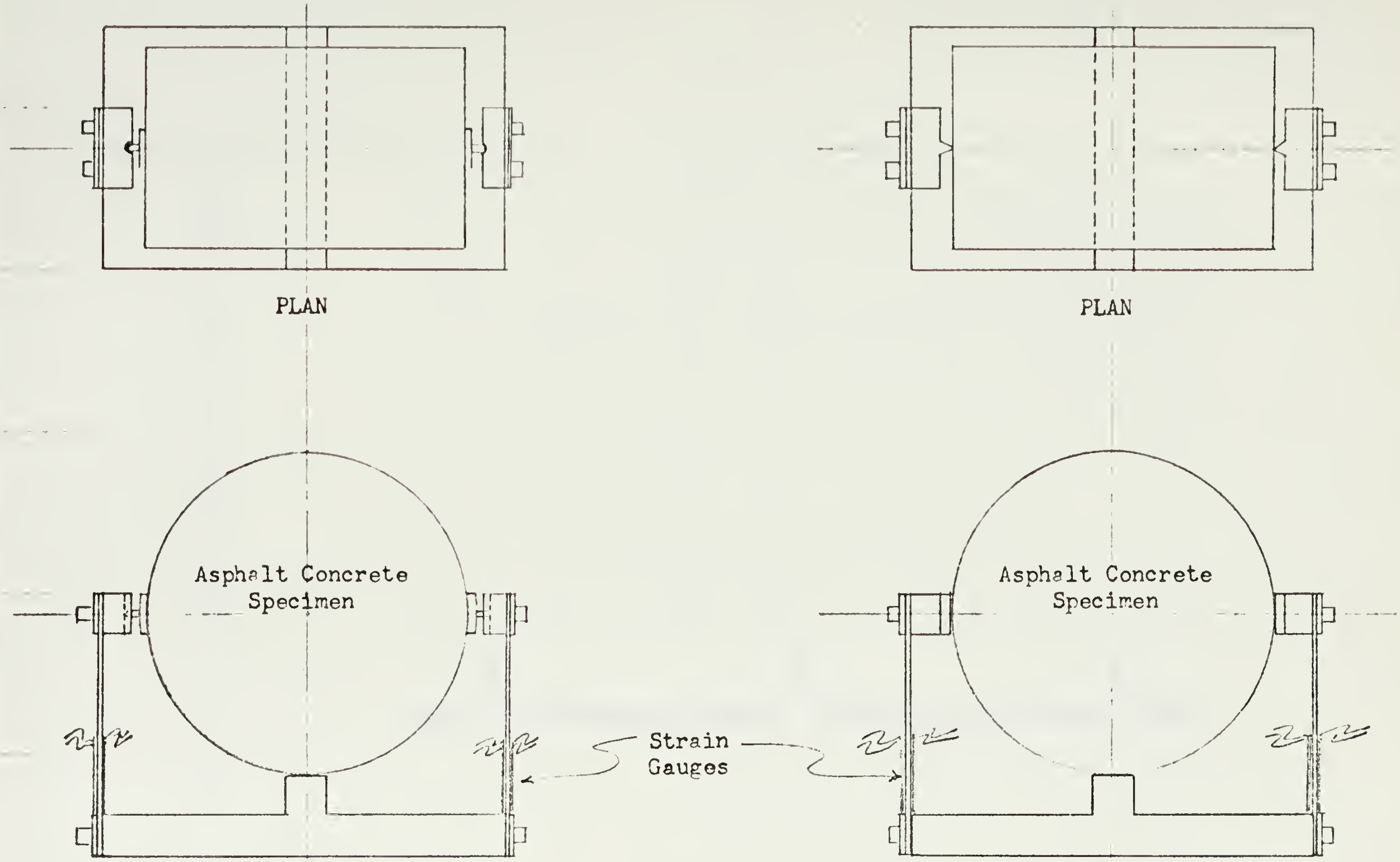


View of resilient modulus device positioned in the repetitive loading apparatus.



View of resilient modulus device positioned in the repetitive loading apparatus with amplifier and recorder connected

FIGURE 5 Resilient Modulus Testing Apparatus



ELEVATION

M_R device utilized for testing specimens subjected to thermal cycle accelerated conditioning

ELEVATION

M_R device utilized for testing specimens subjected to accelerated conditioning at 140° F

FIGURE 6 Resilient Modulus Testing Device

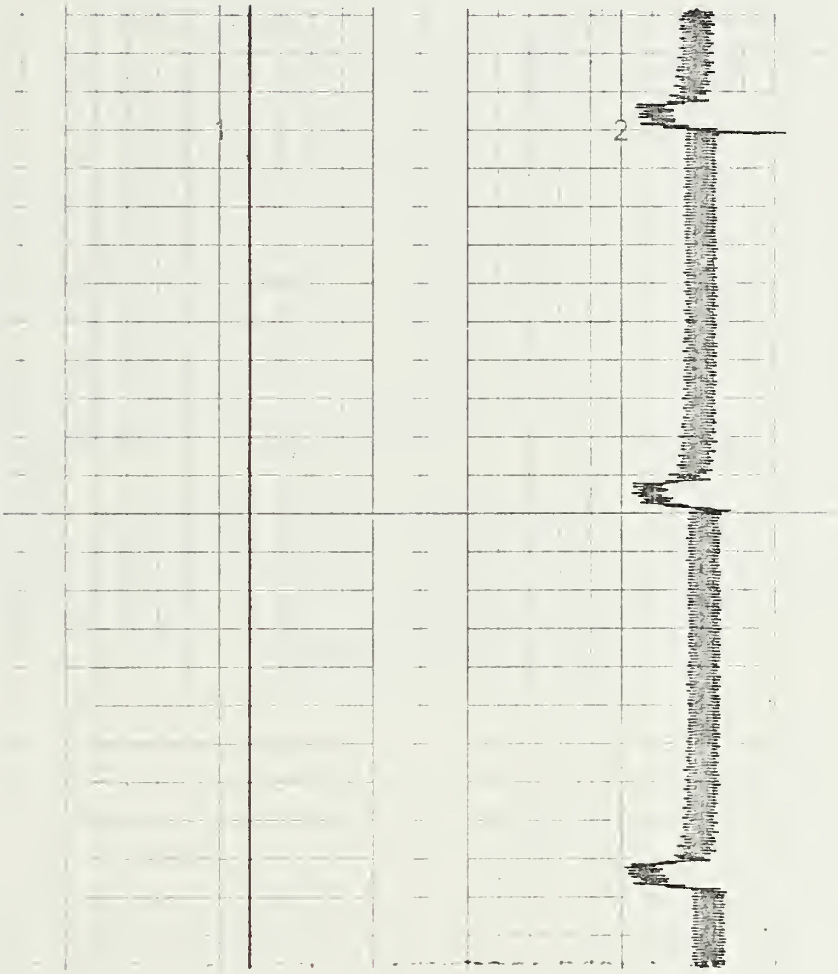


FIGURE 7 Typical Trace From Strip Chart Recorder For Diametral Measurement.

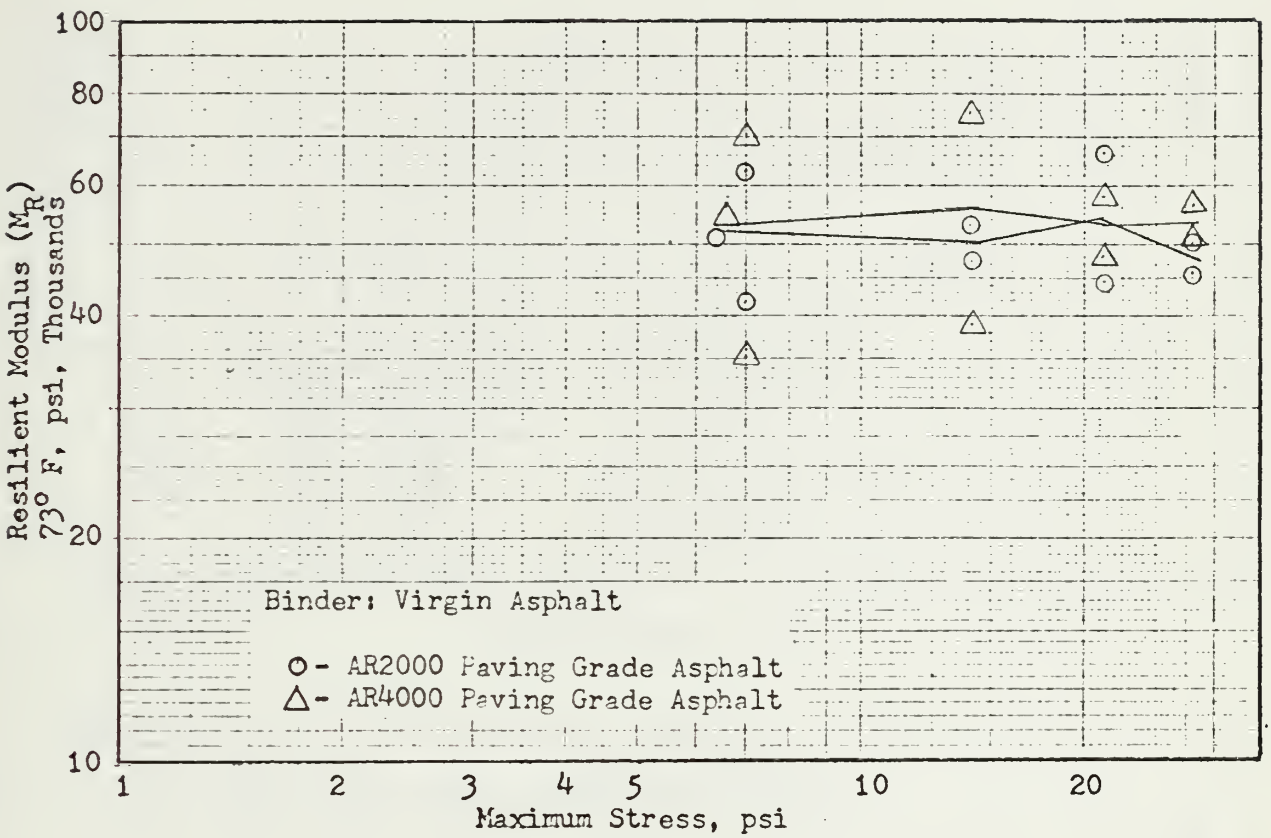
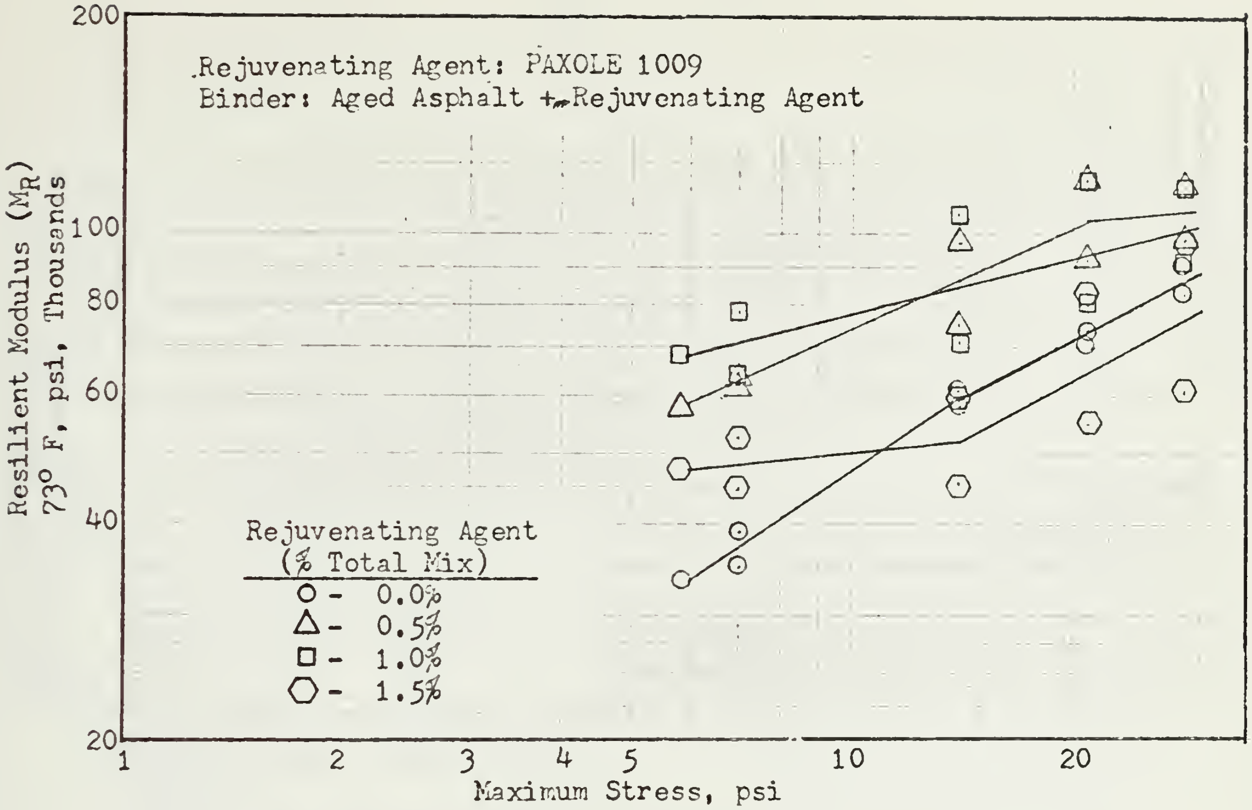


FIGURE 8 Original Resilient Modulus of Asphalt Concrete Specimens Subjected to Vacuum Saturation and Thermal Cycle Accelerated Conditioning



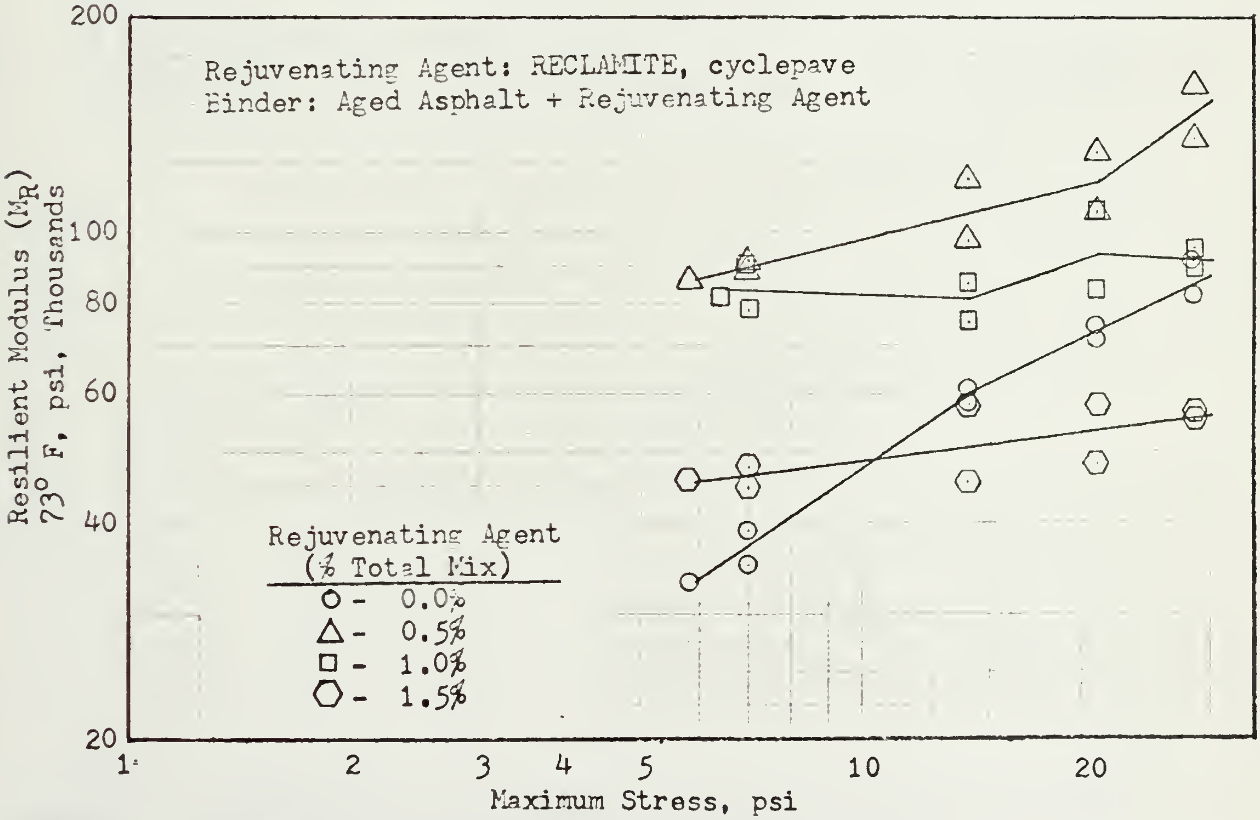


FIGURE 9 Original Resilient Modulus of Recycled Asphalt Concrete Specimens Subjected to Vacuum Saturation and Thermal Cycle Accelerated Conditioning

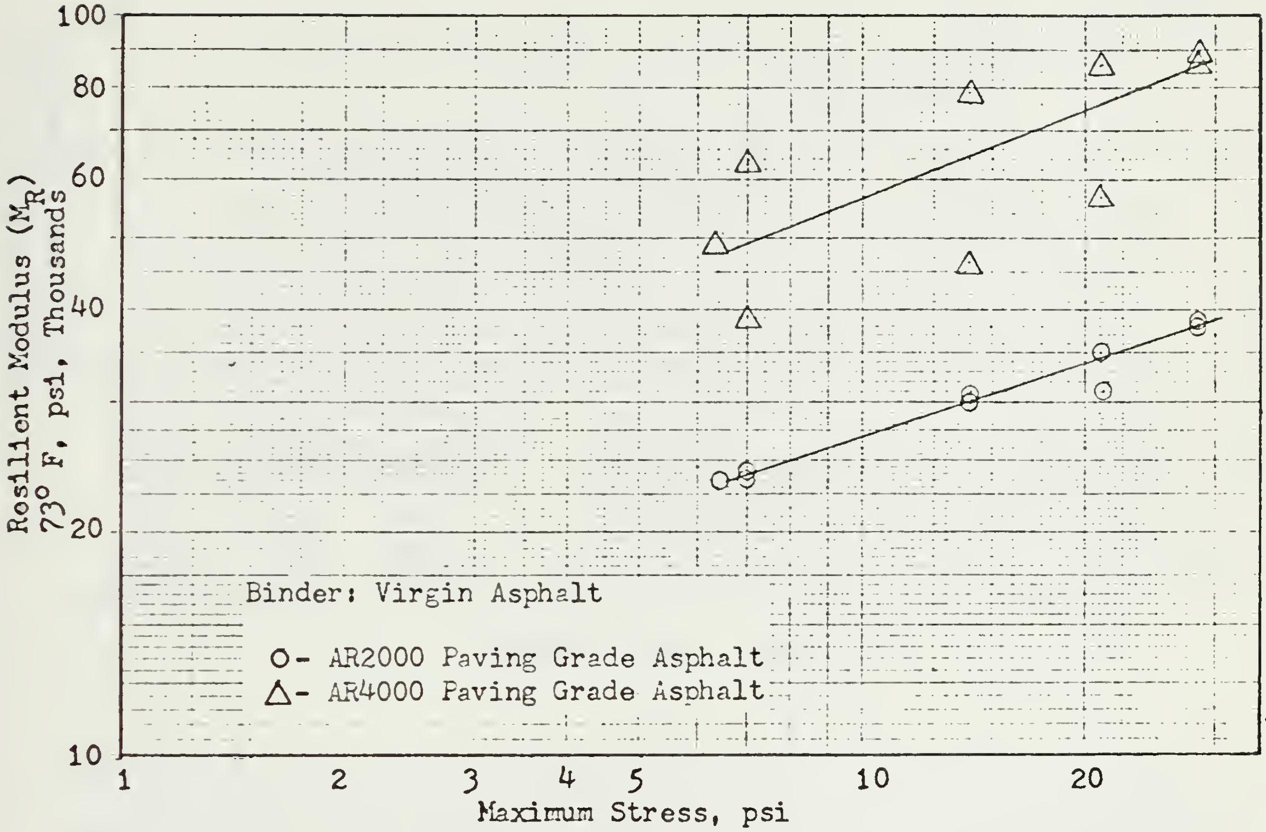
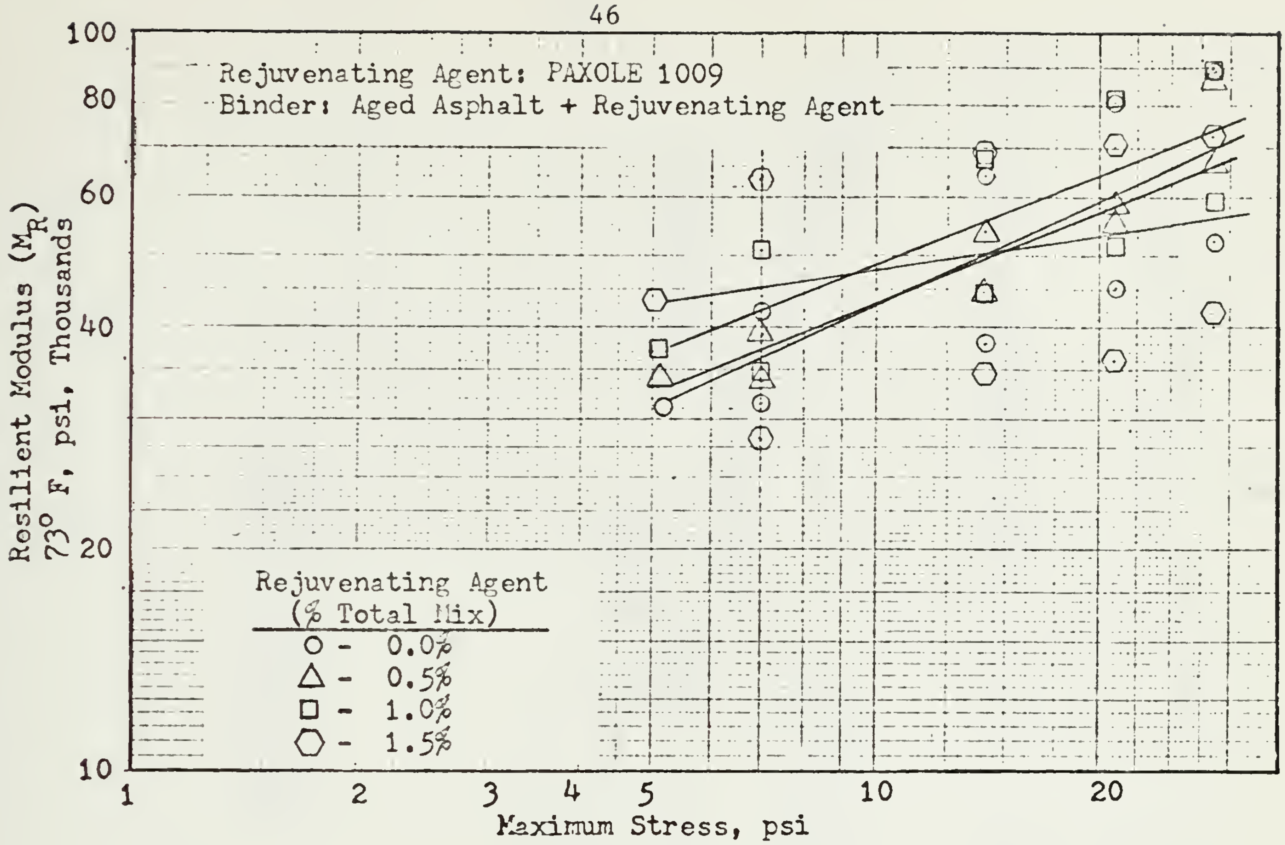


FIGURE 10 Original Resilient Modulus of Asphalt Concrete Specimens Subjected to Accelerated Conditioning at 140° F



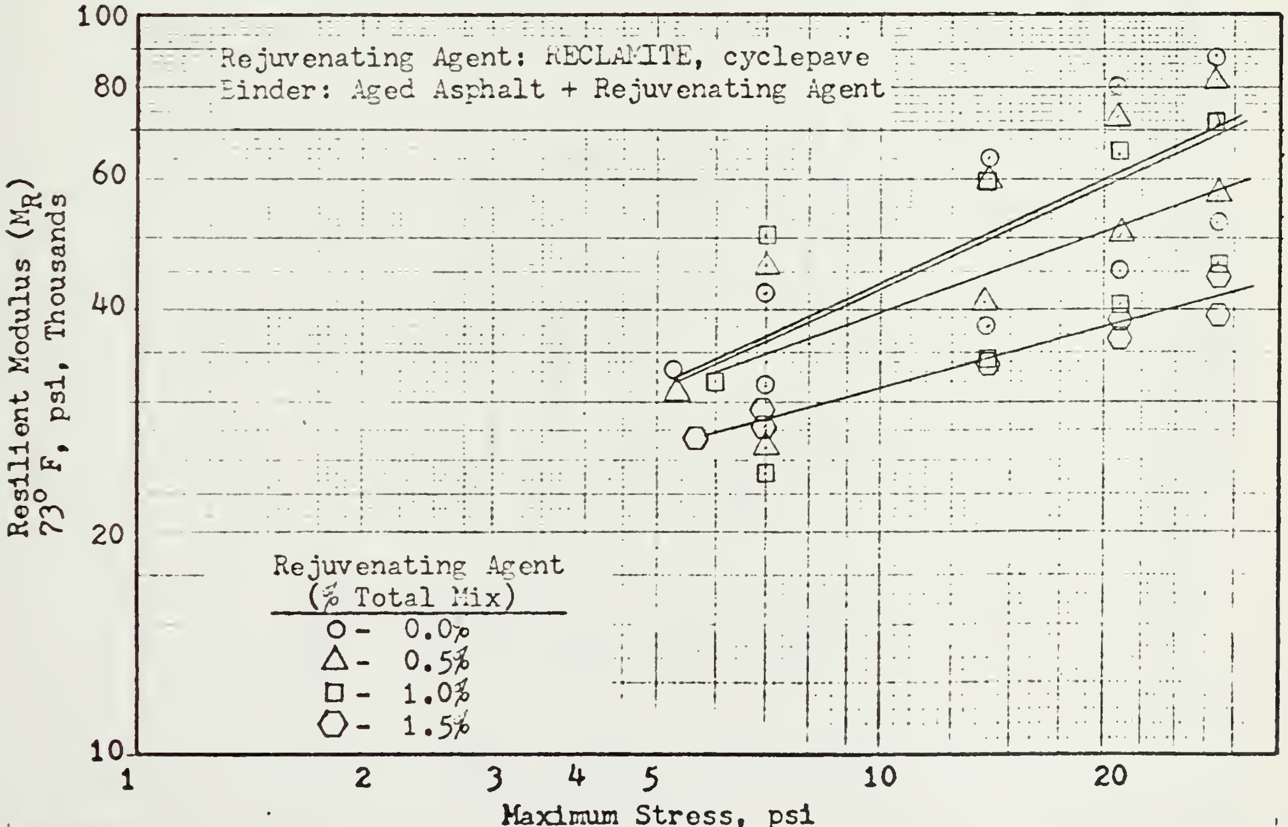


FIGURE 11 Original Resilient Modulus of Recycled Asphalt Concrete Specimens Subjected to Accelerated Conditioning at 140° F

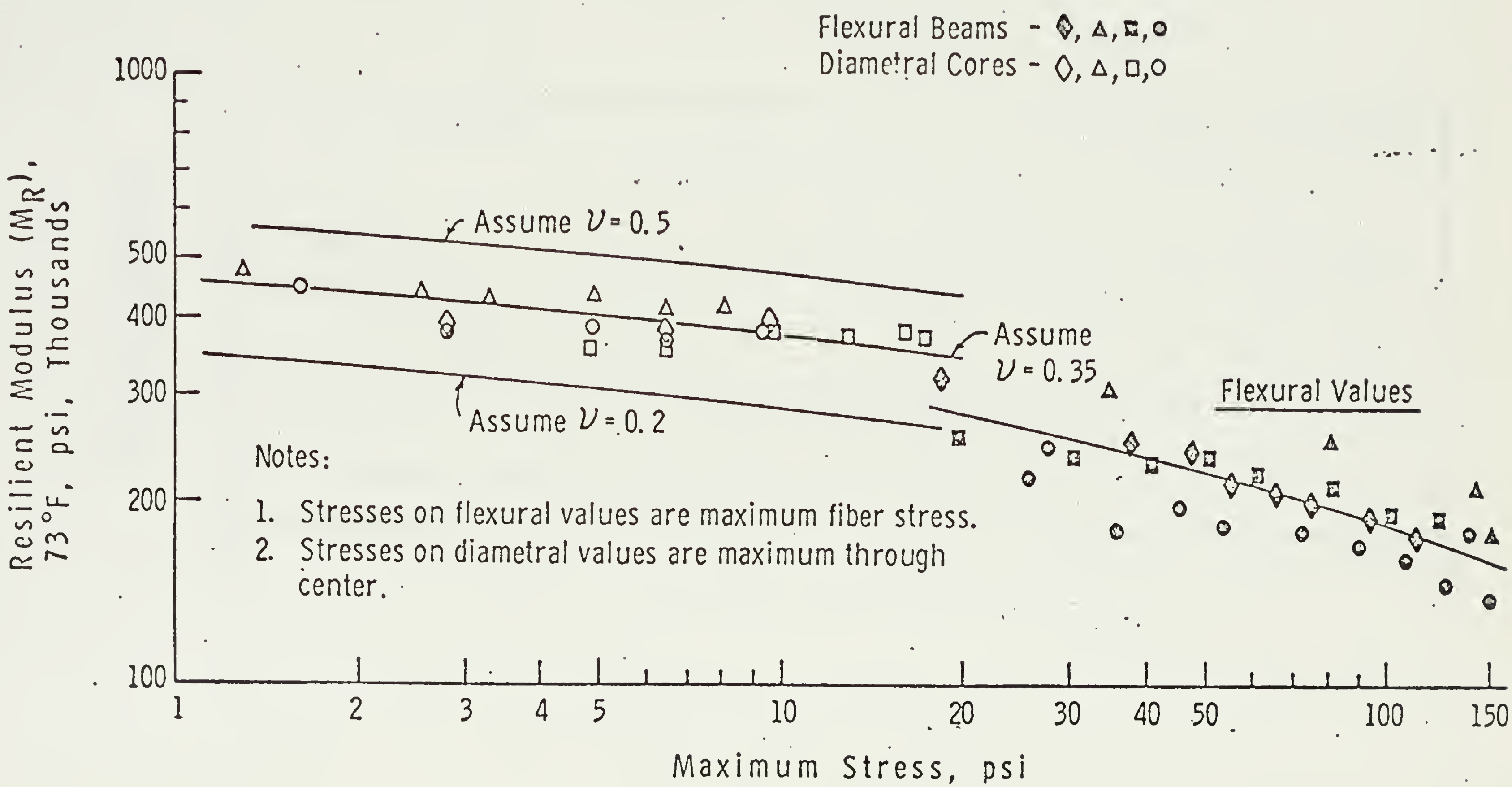


FIGURE 12 Resilient Modulus Obtained By Schmidt Using Flexural and Diametral Methods for Testing[24].

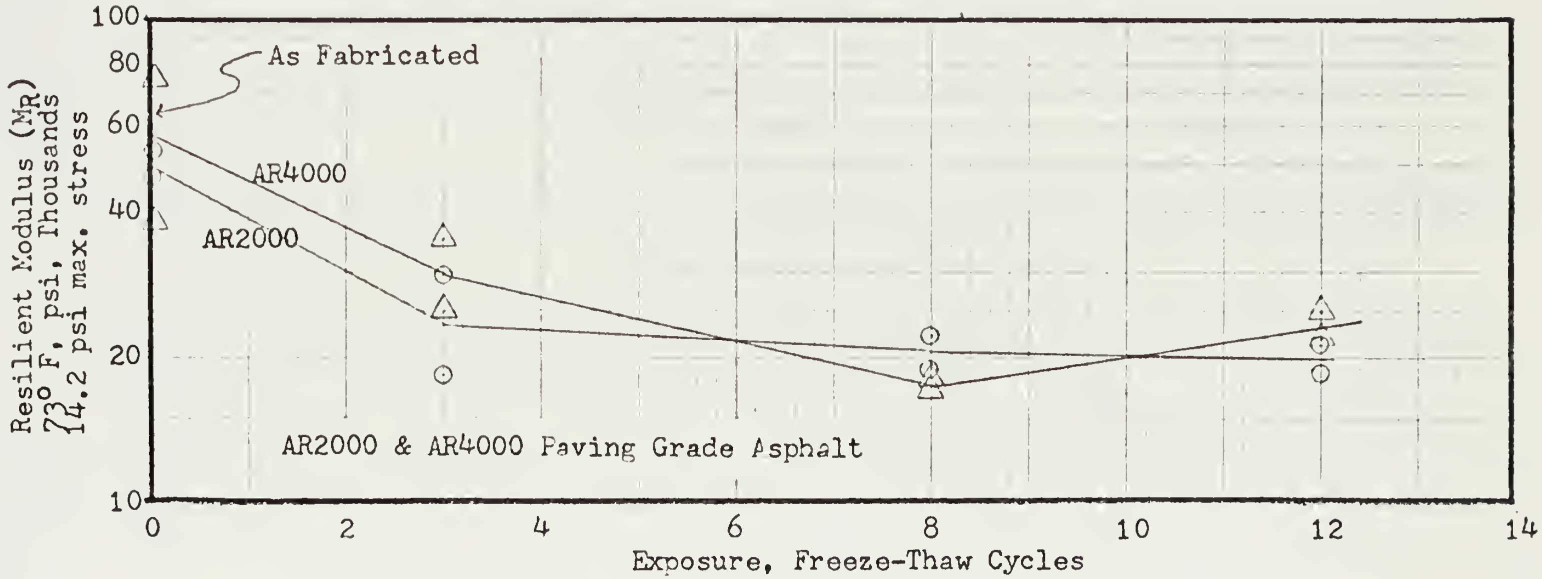


FIGURE 13 Influence of Vacuum Saturation and Thermal Cycle Accelerated Conditioning on Resilient Modulus of Asphalt Concrete Specimens

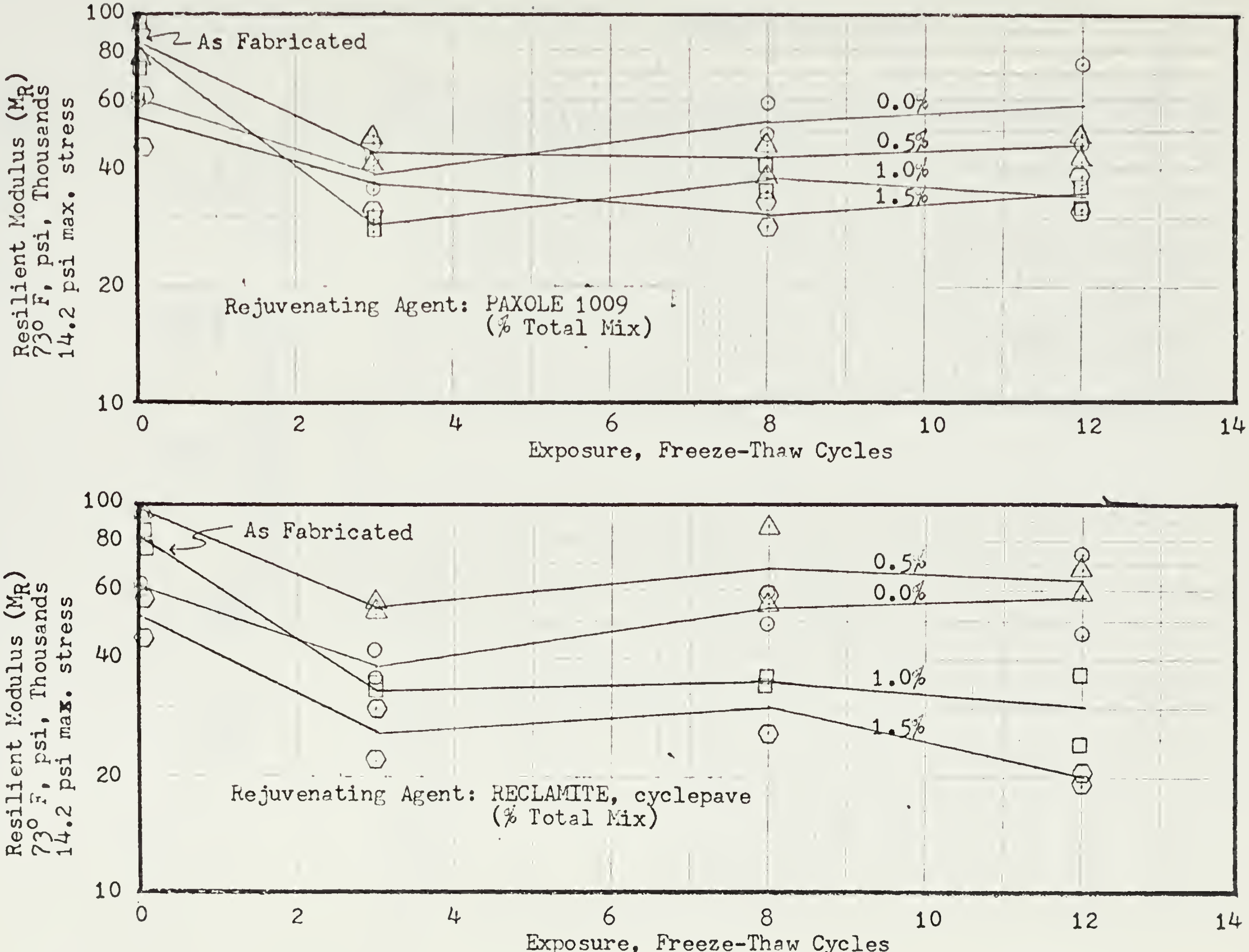
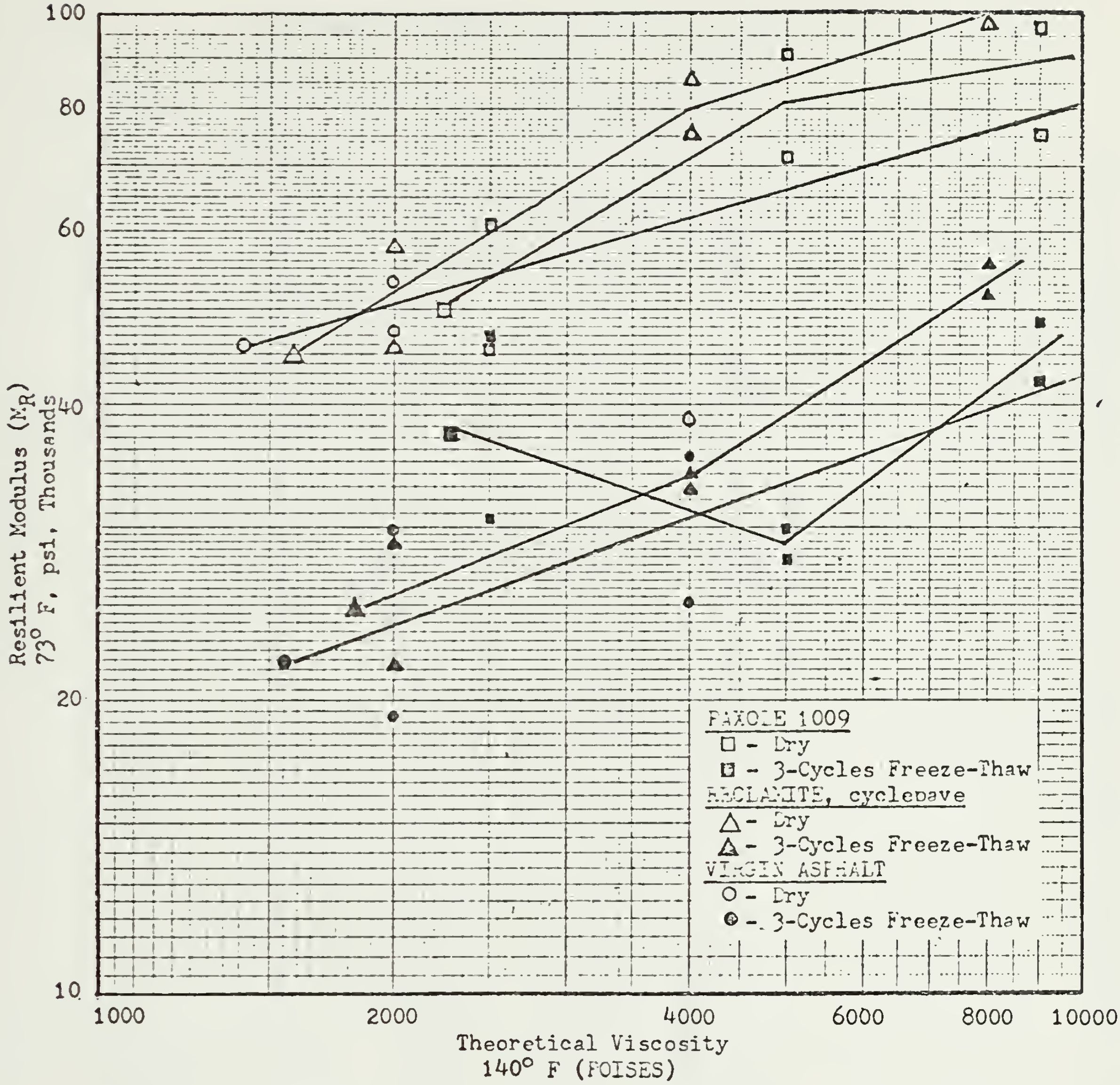


FIGURE 14 Influence of Vacuum Saturation and Thermal Cycle Accelerated Conditioning on Resilient Modulus of Recycled Asphalt Concrete Specimens



NOTE: Theoretical Viscosity obtained from FIG. 3

Rej. Agent (%)	Theoretical Viscosity PAXOLE	RECLAMITE	AR2000	AR4000
0.0	--	--	2000	4000
0.5	9000	8000	--	--
1.0	5000	4000	--	--
1.5	2500	2000	--	--

FIGURE 15 Difference in Original Dry M_R and the M_R After Vacuum Saturation and Thermal Cycle Accelerated Conditioning

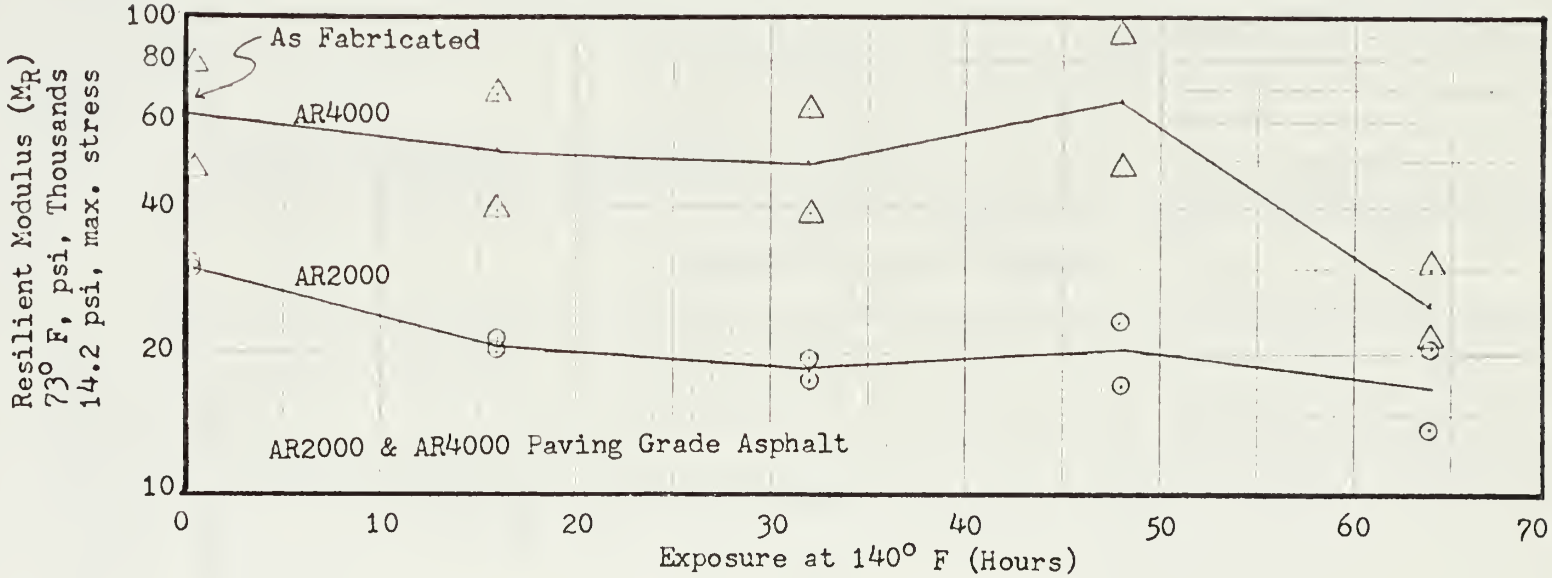


FIGURE 16 Effect of Accelerated Conditioning at 140° F on the Resilient Modulus of Asphalt Concrete Specimens Containing Paving Grade Asphalt

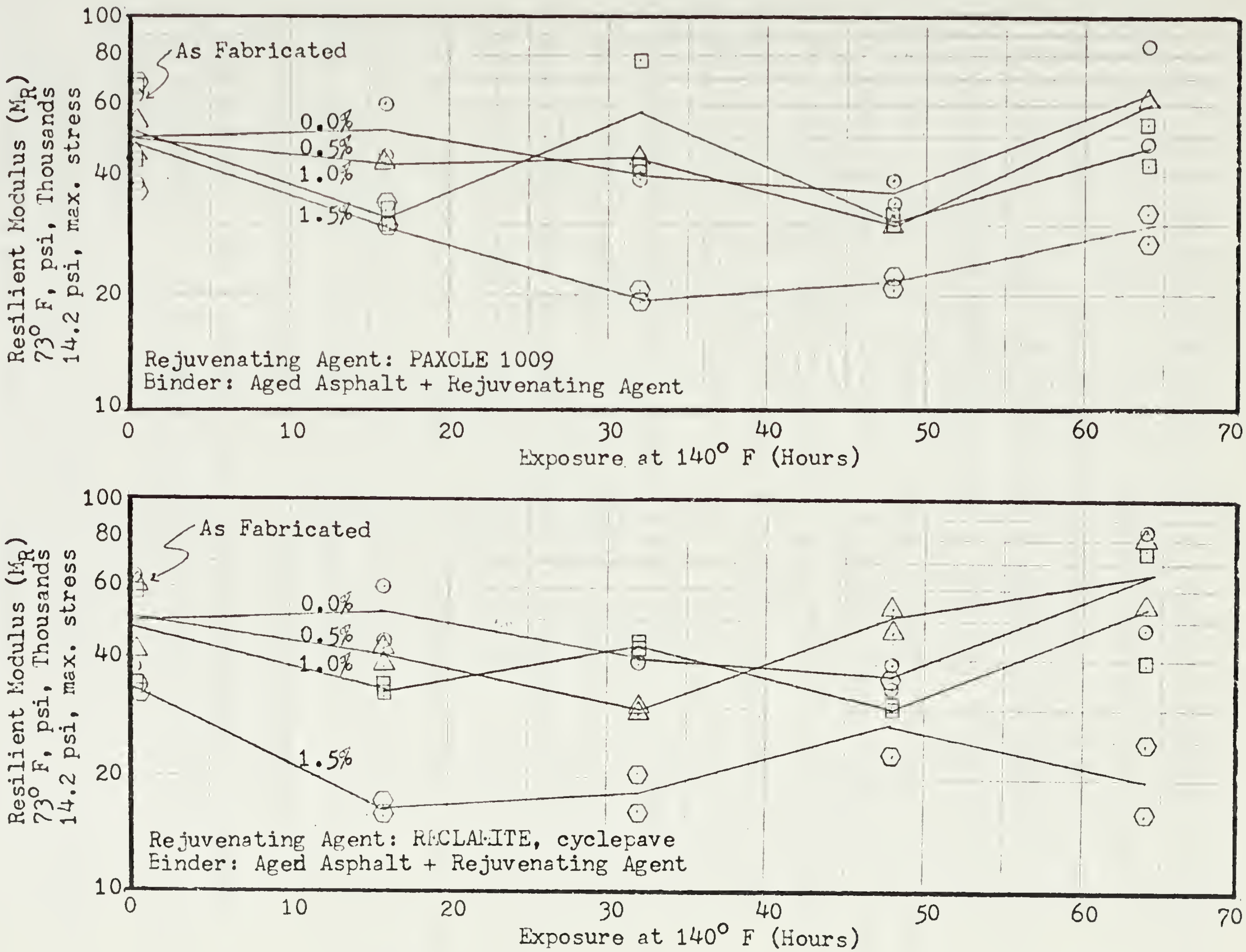


FIGURE 17 Effect of Accelerated Conditioning at 140° F on the Resilient Modulus of Recycled Asphalt Concrete Specimens Containing Rejuvenating Agents

APPENDIX A

DISCUSSION OF THE RESILIENT MODULUS DEVICE

All the resilient modulus tests were conducted utilizing the apparatus shown in Figures 5 and 6. The tests results obtained by utilizing this apparatus provided the data necessary to evaluate the relative changes in the resilient modulus of the specimens subjected to accelerated contitioning and also indicated some generally consistent trends in specimen performance. However, the resilient modulus values obtained by utilizing this apparatus proved to be much lower than what could normally be expected. It is suspected that the low M_R values are a result of the strain gages sensing not only the strain produced by horizontal deformation of the specimen due to vertical loading but also a strain possibly produced by deflection of the base plate of the M_R device along with eccentricity developed from the slightest error in positioning the specimen in the M_R device. In order to eliminate the unwanted strain it is suggested that the device utilized for measuring the horizontal deflection be isolated from the base plate and loading block. This isolation would prevent much of the unwanted strain and permit more flexibility in positioning the specimen. Positioning of the specimen in the M_R device is extremely important. After using each of the methods shown in Figure 6, the contact points affixed to the arm of the M_R device were considered more suitable for testing the asphalt concrete specimens. This method permits the operator to rotate or reposition the specimen.

As can be seen in Figure 7, the trace produced from the strip chart recorder indicated excess "noise" or interference. As a result of the interference the sensitivity settings on the amplifier and recorder were limited to a moderate range. More accurate deformation readings could be

achieved if the interference were eliminated. In an effort to eliminate the interference it is suggested than an electronic filter be installed on the equipment and the equipment be connected to a separate electrical circuit.

Although the resilient modulus device utilized in this research has not yet been perfected, it does provide relative results and shows considerable potential as a practical means for accurately measuring the horizontal deformation necessary to calculate the resilient modulus. Prior to future use of this device it is recommended that the equipment modifications suggested in the foregoing discussion be given some considerations.

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F8937 Fritchen
Laboratory performance of recycled asphalt concrete.